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RESEARCH MEMORANDUM

TURBOJET COMBUSTOR EFFICIENCY WITH CERAMIC-COATED LINERS AND WITH MECHANICAL CONTROL OF FUEL WASH ON WALLS

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TURBOJET COMBUSTOR EFFICIENCY WITH CERAMIC-COATED LINERS AND WITH MECHANICAL CONTROL OF FUEL WASH ON WALLS

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2705

SUMMARY

An investigation was conducted to evaluate two methods of decreasing losses of unevaporated fuel from the combustion zone of turbojet-engine combustors. The first method consisted of installing fuel "dams" on the inner surface of the combustor liner to divert liquid-fuel films on the walls into penetrating air jets. The second method consisted of coating the combustor-liner walls with ceramic to increase surface temperature and hence increase rate of evaporation of liquid fuel. Combustion performance data were obtained with J33 and J47 single combustors at low pressure and varied fuel-air ratio and air-flow rate conditions to compare effects of the combustor modifications on combustion efficiency and flame blow-out.

Results of tests conducted in the J33 single combustor equipped with fuel dams indicated substantial improvements in combustion efficiency at low fuel-flow conditions when the standard fuel nozzle was used; no improvements were observed at high fuel-flow rates. A reduced capacity, narrow-spray-angle fuel nozzle provided improvements in combustion efficiency only at conditions where severe wall wetting occurred. Similar results were obtained in another J33 combustor the liner of which was coated with a dual ceramic coating consisting of a reflective base coat and an insulating cover coat. At conditions representative of actual engine operation at high altitudes, increases in combustion efficiency of 16 and 15 percent were obtained in the J33 combustor with the fuel dams and with the dual ceramic coating, respectively. No further improvement in combustion efficiency resulted from a combination of fuel dams and ceramic coating. Only small effects on combustion efficiency were observed when two other types of ceramic coating were applied to the J33 combustor or when the dual ceramic coating was applied to the J47 combustor.

INTRODUCTION

Operation of turbojet-engine combustors at high-altitude conditions results in reduced combustion efficiency, with attendant increases in engine fuel consumption. Research at the NACA Lewis laboratory and other laboratories has been directed toward an explanation of this performance trend in terms of a single controlling step in the complex combustion process. Results of a number of investigations summarized in reference 1 indicate that losses in combustion efficiency may be attributed to (1) incomplete vaporization of liquid fuel, (2) incomplete mixing of the fuel with proper quantities of air, and (3) incomplete combustion of the vaporized fuel.

2705

Studies conducted in transparent combustors indicate that a considerable quantity of liquid fuel may impinge on the walls of the combustor inner liner; for example, reference 2. Such fuel impingement is the result both of the use of wide-spray-angle fuel nozzles and of the reverse air-flow currents in the upstream combustor region. Under cold-flow conditions a large portion of the resultant fuel film on the wall travelled beyond the combustion zone before reentering the air stream. Studies in another transparent combustor during initial burning (reference 2) substantiated these observations. Although heated combustor walls will promote rapid vaporization of the fuel film, the vapor formed may not enter zones favorable to combustion and thus may constitute a significant loss in fuel available for combustion. Possible reduction in combustion efficiency incurred in this manner is the subject of the research described herein.

Preliminary investigations were conducted to evaluate methods for (1) returning liquid-fuel films on walls to the combustion zone and (2) increasing vaporization of the fuel films on combustor walls. Fuel "dams" were installed on the inner wall of the liner of a J33 single combustor between rows of primary-air-admission holes to redirect the wall fuel films into the primary-air jets. Photographs obtained in a cold-flow transparent combustor, illustrating the effects of these dams on the wall fuel film, are presented herein. The combustor was operated with each of two fuel nozzles having different spray-dispersion characteristics.

An attempt was made to increase the rate of evaporation of the fuel by providing the combustor-liner walls with ceramic coatings. The function of a ceramic coating may be to provide one or both of the following: (1) increased inner-surface temperatures due to insulating effect of the coating, and (2) increased air-scrubbing action due to increased "roughness" of some granular ceramic surfaces. Three coatings were investigated: (1) a dual coating consisting of a reflective base coat and an insulating top coat, (2) a single high-temperature protective coating, and (3) a porcelain-type cement. The first coating was applied to both single J33 and J47 combustor liners; coatings 2 and 3 were applied to the J33 combustor liner only.

Combustion efficiency and flame blow-out limit data were obtained with the standard and the modified combustors at combustor-inlet-air pressures of 8 and 15 inches of mercury absolute, inlet-air temperature of 268° F, and a range of air velocities and fuel-air ratios. Fuel conforming to specification MIL-F-5624A, grade JP-4, was used for all tests. The results obtained with the various combustors are compared to indicate possible explanation for the effects of the modifications on combustor performance.

APPARATUS AND PROCEDURE

Combustors

Two types of single-tubular combustor, one from a J33 and one from a J47 turbojet engine, were used for the investigation reported herein. The installation of the combustors, including air heaters and control equipment, was similar to that described in reference 3. Air flow and fuel flow to each combustor were measured by square-edged orifice plates installed according to A.S.M.E. specifications and by calibrated rotameters, respectively. A sketch of the two combustor installations, showing location and arrangement of the instrumentation planes, is presented in figure 1. Inlet-air pressures were measured by total-pressure rakes. Inlet-air temperatures were determined by bare single-junction iron-constantan thermocouples; exhaust-gas temperatures were measured by single-shielded chromel-alumel thermocouple rakes (reference 3). The axial location of the exhaust-gas thermocouples in each combustor setup corresponded approximately to the position of the turbine blades in the full-scale engine.

Photographs of the inner liners of the two combustors, showing the shape and distribution of the air-admission holes, are presented in figure 2. In both combustors the holes provided for cross-fire tubes were closed. A hollow-cone swirl-type fuel nozzle having a nominal flow capacity of 40 gallons per hour (at 100 lb/sq in. pressure) and a spray angle of 80° was used for most of the J33 combustor tests. Limited tests were also conducted in this combustor with a 15.3-gallon-per-hour 30°-spray-angle nozzle. The J47 combustor was equipped with a wide-flow-range duplex-type fuel nozzle. Standard ignition plugs, in combination with 5000-volt, 60-cycles-per-second transformers, were used in both J33 and J47 combustion tests.

In addition to the J47 and J33 single combustors used for combustion tests, a transparent J33 combustor was used for visual studies of fuel-spray characteristics under cold-flow conditions. A complete description of the transparent-combustor apparatus is presented in reference 2.

Fuel Dams

The fuel dams were installed on the inner surface of the J33 liner and consisted essentially of shallow V-shaped Inconel fences ground at the bottom to fit the contour of the inner surface of the combustor liner, as shown in figure 3. The included angle of the "V" was 90°. The heights and locations of the dams are shown in figure 3. The dams were positioned so that the vertex of the "V" formed by two adjacent dams was located at the center of one of the three small primary-air holes (fig. 3). Each installation consisted of seven dams located 2705
around the inner periphery of the combustor liner so that each dam blocked the wall surface between two adjacent rows of holes. A seal between the liner wall and the bottom edge of the dams was achieved by means of a refractory cement.

In order to accommodate the fuel dams in all three positions, it was necessary to close two air-cooling louvers located just upstream of the normal position of the cross-fire tubes. In order to obtain a true comparison of the effect of the dams, check tests were made with this combustor modification before installation of the fuel dams.

Ceramic Coatings

The following ceramic coatings were investigated:

(1) A dual coating consisting of a reflective base coat high in silica content (Univ. of Ill. frit No. 285-1) and an insulating cover coat high in alumina content (Univ. of Ill. frit No. 117-23).

(2) A liquid-porcelain type cement (Sauereisen No. 1).

(3) A mixture of Sauereisen No. 1 and a high-temperature protective coating (Saverite 4000).

A description of ceramic coating 1 is presented in references 4 and 5. Coating 1 was applied to both the J33 and J47 combustor liners, while 2 and 3 were used on the J33 liner only. Photographs of the J33 and J47 liners coated with ceramic 1 are presented in figure 4. Both inner and outer surfaces of the liners were coated in all cases.

The performance of the J33 and J47 liners coated with ceramic 1 was compared with the performance of other J33 and J47 liners of the same respective manufacturer's model number. No geometrical differences between the two liners were detected. Ceramic coatings 2 and 3 were investigated on a different J33 liner of the same model number. Comparison tests with the uncoated liner were made after removal of coating 2 and before application of coating 3.

Test Conditions

Combustion-efficiency data were obtained for a range of fuel-air ratios at each of the following test conditions:

Condition	Combustor-inlet total pressure (in. Hg abs)	Combustor-inlet total temperature (°F)	Air flow per unit frontal area[a] (lb/(sec)(sq ft))
1	15	268	2.78
2	8	268	1.485
3	15	268	2.14
4	15	268	3.62

[a]Based on maximum cross-sectional area of combustor housing (0.48 sq ft for J47 and 0.267 sq ft for J33 combustor).

Test conditions 1 and 2 simulate inlet-air conditions encountered in typical turbojet engines at high altitudes and high flight speeds. Conditions 3 and 4 represent air-flow rates about 23 percent below and 30 percent above current operation, respectively.

Combustion efficiency was determined as the ratio of actual enthalpy rise across the combustor to the enthalpy supplied by the fuel and was computed by the method described in reference 6. In addition to combustion-efficiency data, rich combustor blow-out limits were recorded.

MIL-F-5624A, grade JP-4 fuel was used for all combustion tests reported herein. Physical properties of the fuel are presented in table I. The simulated tests in the transparent combustor were conducted with water in place of fuel in order to obtain more distinct photographs.

RESULTS AND DISCUSSION

The combustion efficiency and flame blow-out data obtained in the J33 and J47 combustors at various combustor-inlet conditions are presented in tables II and III.

Effect of Fuel Dams

A representative installation of two fuel dams was first made in the cold-flow transparent J33 combustor. Photographs obtained at conditions approximating test condition 3 and two water-flow rates, with the 40-gallon-per-hour nozzle, are presented in figure 5. It is noted that considerable wall wetting has occurred upstream of the dams. The dams redirected a large part of the liquid film into the penetrating air-admission hole upstream of the dam. Most of the wall wetting that appears downstream of the dams resulted from travel of liquid from other peripheral areas not provided with dams in this test installation.

The effect of fuel dams on combustion efficiency and flame blow-out is shown in figure 6 for three air-flow rates. Substantial increases in combustion efficiency resulted from the use of fuel dams at low fuel-air ratios. At a fuel-air ratio of 0.012 and inlet-air condition 1 (representative of typical engine operation) an increase in combustion efficiency of 16 percent was obtained (fig. 6(b)). At high fuel-air ratios no improvement was noted. Since losses in combustion efficiency can be attributed to causes other than the loss of liquid fuel along the combustor walls, it is conceivable that at the high fuel-air ratios the dams reached the limit of their effectiveness, and no further improvement in combustion efficiency could be expected from their use. Size and location of the fuel dams, for the range covered, had no significant effect on combustion efficiency except at the high air-flow condition, where the dams located farthest downstream produced a smaller increase in efficiency than did the others.

Combustor blow-out data in figure 6 indicate that a reduction of the rich blow-out limit resulted from the use of fuel dams. This reduction may possibly be attributed to the enrichment of the primary combustion zone with the use of fuel dams.

Since a narrow-spray-angle nozzle would be expected to produce less fuel impingement than a wide-spray-angle nozzle, a 15.3-gallon-per-hour, 30°-angle nozzle was substituted for the standard 40-gallon-per-hour, 80°-angle nozzle used in the previous tests. The results, shown in figure 7, indicate that at the low air-flow rate (2.14 lb/(sec)(sq ft)) fuel dams improved combustion efficiency only slightly; while at the other two air flows (2.78 and 3.62 lb/(sec)(sq ft)) substantial improvement was obtained. Visual observations made in the transparent combustor with water-flow conditions indicated that at the low air-flow rate wall wetting was insignificant, while at the higher flow rates appreciable wetting occurred. In the following table the results of this visual study are compared with combustion-efficiency data obtained in an actual combustor:

Air-flow rate (lb/(sec)(sq ft))	Simulated fuel-air ratio	Observed degree of wall wetting	Increase in combustion efficiency (percent)
2.14	0.0145	None	0
2.14	.0220	Slight	7
2.78	.0115	Slight	0
2.78	.0209	Considerable	12
2.78	.0242	Considerable	10
3.62	.010	Considerable	8
3.62	.020	Considerable	14

It can be seen from the table that wherever considerable wall wetting occurred, installation of fuel dams increased combustion efficiency noticeably. The photographs in figure 8, obtained at the low-air-flow condition, show that with the wide-spray-angle nozzle considerable wetting occurred, while with the narrow-spray-angle nozzle wall-wetting was insignificant. Inspection of figures 6 and 7 shows that under these conditions the fuel dams produced substantial improvement in combustion efficiency with the wide-angle nozzle, while with the narrow-angle nozzle no improvement was noted.

Comparison of figures 6 and 7 also shows that, in general, combustion efficiencies obtained with the narrow-spray-angle nozzle were considerably lower than those obtained with the wide-spray-angle nozzle. In this case losses in combustion efficiency may be the result of increased axial penetration of fuel droplets and, hence, decreased fuel-droplet residence time in the combustion zone.

The relatively short period of operation with the fuel dams did not produce any noticeable deterioration or warping of the dams.

Effect of Ceramic Coatings

J33 combustor. - The results obtained in the J33 combustor with ceramic coating 1 at all four test conditions are presented in figure 9. A 40-gallon-per-hour fuel nozzle was used in these tests. At most low fuel-air-ratio conditions, large increases in combustion efficiency were obtained with the ceramic-coated liner. At a fuel-air ratio of 0.012 and inlet-air condition 1 (representative of typical engine operation) an increase in combustion efficiency of 15 percent was obtained. At the high-air-flow condition the increase was only slight. At all conditions the effects of the coating on combustion efficiency decreased with increases in fuel-air ratio. Rich combustor blow-out limits were reduced somewhat with the ceramic-coated liner. The coated and uncoated liners represent two individual liners which, as far as could be determined by rough measurement, were identical. Although small differences in performance may have existed between the original liners, the increases noted in figure 9 are far too great to be attributed to any difference in liners.

The results obtained with ceramic coatings 2 and 3 at the same test conditions are shown in figure 10. Coating 3 produced a measurable increase in combustion efficiency at test conditions 1, 3, and 4; although the increase, in general, was less than that obtained with coating 1. Coating 2 produced no noticeable increase in combustion efficiency at any condition. As in the case of coating 1, rich combustor blow-out limits were, in general, obtained at somewhat lower fuel-air ratios with coatings 2 and 3 than with the uncoated combustor.

Although the corrosion-protecting and temperature-resisting properties of ceramic coatings have been studied quite extensively, little information is available as to their effect on the combustion process. One possibility that suggests itself is that ceramic coatings might increase the rate of evaporation of the fuel film on the wall and hence increase combustion efficiency. Another possibility is the reflection of radiant energy from the liner walls into the liquid-fuel droplets. However, the results of a theoretical analysis presented in reference 7 show this effect to be of only minor importance. Increased rate of evaporation of the fuel impinging on the wall could be brought about by increased inner-surface temperatures resulting from the insulating effect of ceramic coatings and by increased air-scrubbing action due to increased surface roughness. The greater effectiveness of ceramic coatings at the low fuel flows, where spray characteristics are poor and hence evaporation rates are low, is in agreement with this concept. The reasons for the difference in effectiveness of the various coatings are not readily apparent, but might be the result of differences in their thermal properties, such as thermal conductivity and emissivity. At the surface temperatures encountered in these investigations, catalytic effects would probably not be an important consideration.

<u>J47 combustor</u>. - Results obtained with ceramic coating 1 in the J47 combustor at all four test conditions are presented in figure 11. Only small improvements in combustion efficiency resulting from the ceramic coating were noted. The lack of improvement in combustion efficiency obtained with coating 1 in this combustor, compared with the results obtained in the J33 combustor, may be understood if the principal function of ceramic coatings in the combustion process is considered to be increased rate of evaporation of the fuel film on the liner wall. Fuel impingement on the walls is not as serious a problem in the J47 combustor as in the J33 combustor for several reasons. Comparison of figures 2(a) and 2(b) shows that the surface of the J47 liner is broken up to a much greater extent by holes and louvers than that of

the J33 liner; hence, the possible loss of liquid fuel along the liner walls is greatly diminished. Furthermore, the larger diameter of the J47 liner should decrease the degree of fuel impingement on the walls. Finally, deterioration of spray characteristics normally encountered at low fuel flows should not be nearly as pronounced in the J47 combustor because of the use of a duplex fuel nozzle.

Effect of Combination of Fuel Dams and Ceramic Coatings

2705

Analysis of the data obtained in both combustors with ceramic coatings and fuel dams indicates the possibility that both design modifications performed essentially the same function, that of preventing the loss of liquid fuel along the liner walls. A combination of the two combustor modifications would not, therefore, be expected to provide any further improvements in combustion efficiency. The results of tests in the J33 combustor, coated with ceramic 1 and equipped with fuel dams, are presented in figure 12. A 40-gallon-per-hour fuel nozzle was used in these tests. The data clearly indicate that no increase in combustion efficiency over that obtained with either modification alone resulted from the combination of ceramic coating and fuel dams. Rich blow-out limits were, in general, obtained at somewhat lower fuel-air ratios than with either modification alone or with the standard combustor, a trend which may be attributed to the enriching of the primary combustion zone.

Effect of Ceramic Coating on Carbon Deposition

The effect of ceramic coating 1 on combustion-chamber carbon deposition was investigated briefly. An uncoated and the coated liner were operated at conditions which had been used in previous studies of carbon deposition (reference 3), simulating 90 percent of normal rated engine speed and a 20,000-foot altitude for a period of 4 hours. A highly aromatic fuel deposited similar quantities of carbon in both liners (approximately 35 g). However, while the deposits in the uncoated liner were evenly distributed over the upstream area of the liner and dome, a large portion of the deposits in the coated liner was concentrated in two formations, as shown in figure 13. The carbon formations were supported on the wall at points where some of the coating had disintegrated. Most of the upstream area of the ceramic-coated liner was clean. Cooling of the liner following completion of this test caused considerable spalling of the ceramic coating. These results suggest that a durable continuous ceramic coating may decrease carbon deposition.

SUMMARY OF RESULTS

From an investigation of two combustor design methods for decreasing the losses of unevaporated fuel from the combustion zone of turbojet combustors at high-altitude operating conditions the following results were obtained:

1. In a J33 single combustor equipped with fuel dams, substantial improvements in combustion efficiency were obtained with the standard fuel nozzle at low fuel-flow rates; no improvements were observed at high fuel-flow rates. A reduced-capacity, narrow-spray-angle fuel nozzle provided improvements in combustion efficiency only at conditions where severe wall wetting occurred. 2705

2. Similar results were obtained in another J33 combustor whose liner was ceramic-coated with a reflective base coat and an insulating cover coat.

3. At conditions representative of actual engine operation at high altitude, increases in combustion efficiency of 16 and 15 percent were obtained in the J33 combustor with the fuel dams and with the dual ceramic coating, respectively.

4. No further improvement in combustion efficiency resulted from a combination of fuel dams and ceramic coating.

5. Only small effects on combustion efficiency were observed when two other types of ceramic coating were applied to the J33 combustor or when the dual ceramic coating was applied to the J47 combustor.

CONCLUDING REMARKS

The results suggest that the effects of the fuel dams and of the ceramic coating on combustion were similar. Thus, the dams diverted liquid fuel from the fuel film on the liner walls to the combustion zone, and the ceramic coating increased the rate of evaporation of the fuel film by increasing liner-surface temperature. The fuel dams and the ceramic coating were most effective at conditions where (1) poor fuel atomization retarded fuel evaporation and (2) air-flow currents and spray angle caused excessive wall wetting. It is concluded that fuel wetting on turbojet-combustor walls may result in a substantial loss in combustion efficiency. Combustors should, therefore, be designed to avoid excessive wetting; or if such wetting is unavoidable, methods similar to those described herein may be used to minimize deleterious effects on combustion efficiency.

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2705

TABLE I - FUEL ANALYSIS

Fuel properties	MIL-F-5624A, grade JP-4 (NACA fuel 52-53)
A.S.T.M. distillation D86-46, (°F)	
Initial boiling point	136
Percent evaporated	
5	183
10	200
20	225
30	244
40	263
50	278
60	301
70	321
80	347
90	400
Final boiling point	498
Residue (percent)	1.2
Loss (percent)	0.7
Aromatics, (percent by volume)	
A.S.T.M. D-875-46T	8.5
Silica gel	10.7
Specific gravity	0.757
Viscosity (centistokes at 100° F)	0.762
Reid vapor pressure (lb/sq in.)	2.9
Hydrogen-carbon ratio	0.170
Net heat of combustion	18,700

TABLE II - PERFORMANCE DATA OF J33 COMBUSTOR

[Fuel-nozzle capacity, 40 gal/hr]

Run	Combustor-inlet total pressure (in. Hg abs)	Combustor-inlet temperature (°R)	Air flow (lb/sec)	Combustor reference velocity (ft/sec)	Fuel flow (lb/hr)	Fuel-air ratio	Mean combustor-outlet temperature (°R)	Combustion efficiency (percent)
Standard combustor								
1	15.0	726	0.568	77.8	17.1	0.00836	1040	50.7
2	15.1	726	.567	77.7	24.4	.01195	1240	59.2
3	15.1	726	.568	77.8	29.2	.01428	1420	68.0
4	15.0	727	.569	77.9	33.1	.01616	1570	74.0
5	15.0	727	.569	77.9	39.4	.01924	1770	78.4
6	15.1	726	.569	77.9	43.5	.02124	1910	81.6
7	15.0	726	.569	77.9	49.0	.02393	2075	83.9
8	15.0	728	.740	101.4	20.1	.00755	1070	61.1
9	15.1	728	.741	101.6	28.1	.01053	1260	69.3
10	15.1	728	.741	101.6	33.9	.01271	1410	74.7
11	15.1	727	.742	101.7	39.4	.01475	1570	80.7
12	15.0	727	.743	101.8	47.0	.01757	1760	84.5
13	15.0	728	.744	101.9	54.2	.02024	1915	85.7
14	15.0	728	.743	101.8	61.5	.02299	2070	86.6
15	15.0	729	.962	131.8	33.0	.00953	1265	77.0
16	15.1	729	.962	131.8	40.4	.01167	1410	81.0
17	15.1	729	.962	131.8	49.5	.01429	1565	82.5
18	15.1	729	.962	131.8	60.0	.01733	1755	85.1
19	15.0	729	.962	131.8	70.8	.02044	1910	84.5
20	15.0	729	.963	131.9	83.1	.02397	2070	83.2
21	15.0	729	.963	131.9	29.8	.00860	1210	76.1
22	7.9	727	.395	101.5	22.2	.01561	1250	46.6
23	8.0	727	.395	101.5	25.0	.01757	1425	56.1
24	8.0	726	.398	102.1	27.6	.01927	1565	62.2
25	8.0	727	.398	102.1	32.0	.02235	1765	67.7
26	8.0	727	.397	102.0	35.0	.02448	1910	71.4
27	8.0	727	.397	102.0	37.4	.02615	2005	72.8
28	8.0	727	.398	102.1	24.4	.01704	1410	56.5
29	8.0	727	.397	101.9	21.2	.01485	1260	49.9
30	15.0	727	.742	101.7	33.6	.0126	1450	80.1
31	15.1	726	.742	101.7	42.5	.0159	1650	82.8
32	15.0	727	.741	101.7	51.3	.0192	1855	85.4
33	15.0	726	.743	101.8	59.2	.0221	2010	85.8
34	15.1	726	.741	102.1	65.8	.0245	2155	87.3
35	15.0	726	.741	101.7	75.2	.0282	2305	85.3
36	15.0	726	.742	101.7	77.2	.0289	2325	84.5
37	14.9	727	.963	131.9	52.7	.0152	1605	81.9
38	15.0	727	.965	132.2	62.7	.0180	1760	82.7
39	15.0	726	.963	131.9	67.9	.0196	1860	84.2
40	15.0	727	.963	131.9	78.6	.0227	2010	83.6
41	15.0	726	.964	132.0	86.5	.0249	2070	80.6
42	15.0	725	.964	132.0	93.4	.0269	2105	77.1
43	15.0	727	.570	78.0	39.7	.0193	1785	79.4
44	15.0	726	.570	78.0	33.6	.0164	1555	71.7
45	15.0	728	.568	77.8	28.8	.0141	1400	66.6
46	15.0	727	.568	77.8	28.1	.0137	1380	66.5
47	15.0	727	.572	78.3	43.1	.0209	1915	83.3
48	15.0	726	.572	78.3	48.2	.0234	2035	83.0
49	15.0	727	.572	78.3	53.2	.0258	2165	83.8
50	15.0	726	.569	78.0	57.9	.0283	2280	83.6
51	15.0	726	.569	78.0	58.8	.0287	2300	83.6

TABLE II - PERFORMANCE DATA OF J33 COMBUSTOR - Continued

[Fuel nozzle capacity, 40 gal/hr]

Run	Combustor-inlet total pressure (in. Hg abs)	Combustor-inlet tempera-ture (°R)	Air flow (lb/sec)	Combustor reference velocity (ft/sec)	Fuel flow (lb/hr)	Fuel-air ratio	Mean combustor-outlet tempera-ture (°R)	Combustion efficiency (percent)
Standard combustor with upstream louvers closed								
52	15.0	725	0.964	132.0	42.4	0.0122	1425	79.9
53	15.0	726	.963	131.9	47.6	.0137	1515	81.0
54	15.0	726	.964	132.0	55.3	.0159	1650	82.8
55	15.0	726	.964	132.0	62.6	.0180	1770	83.6
56	15.0	726	.964	132.0	70.1	.0202	1910	85.7
57	15.0	726	.964	132.0	78.0	.0225	2020	85.1
58	15.0	726	.964	132.0	83.7	.0241	2110	85.7
59	15.0	726	.964	132.0	89.1	.0257	2160	83.8
60	15.0	729	.963	131.9	38.4	.0111	1360	78.7
61	15.0	726	.745	102.1	41.8	.0156	1605	80.0
62	15.0	726	.745	102.1	50.1	.0187	1785	81.9
63	15.0	726	.745	102.1	56.3	.0210	1930	84.1
64	15.0	726	.745	102.1	64.9	.0242	2115	85.7
65	15.0	726	.745	102.1	71.0	.0265	2240	86.4
66	15.0	726	.745	102.1	76.2	.0284	2335	86.5
67	15.0	726	.745	102.1	38.0	.0142	1525	79.2
68	15.0	726	.745	102.1	32.6	.0122	1385	75.1
69	15.0	724	.572	78.3	36.3	.0176	1610	71.9
70	15.0	726	.575	78.8	41.7	.0201	1785	76.5
71	15.0	726	.575	78.8	48.6	.0235	1990	79.7
72	15.1	726	.575	78.8	55.1	.0266	2180	82.4
73	15.0	725	.572	78.3	62.6	.0304	2380	83.7
74	15.0	725	.572	78.3	67.1	.0326	2470	83.1
75	15.0	725	.575	78.8	70.8	.0342	2535	82.8
76	15.0	726	.575	78.8	32.6	.0157	1495	69.1
77	15.0	726	.572	78.3	28.8	.0140	1370	64.2
78	15.0	726	.572	78.3	24.6	.0119	1250	60.8
Standard combustor with small dams $3\frac{5}{8}$ inches from nozzle tip								
79	15.0	726	0.570	78.0	35.3	0.0172	1740	84.7
80	15.0	726	.571	78.2	40.8	.0198	1900	86.5
81	15.0	724	.571	78.2	48.6	.0236	2070	86.2
82	15.0	729	.571	78.2	53.8	.0262	2210	85.3
83	15.0	729	.571	78.2	59.9	.0291	2330	84.1
84	15.0	728	.571	78.2	62.1	.0302	2370	83.5
85	15.0	727	.571	78.2	30.2	.0147	1590	83.0
86	15.0	727	.571	78.2	27.1	.0132	1480	79.9
87	15.0	728	.572	78.3	24.0	.0117	1380	77.3
88	15.0	729	.743	101.8	37.6	.0141	1620	89.4
89	15.0	728	.743	101.8	41.7	.0156	1720	90.9
90	15.0	727	.743	101.8	49.3	.0184	1870	90.2
91	15.0	725	.743	101.8	54.7	.0204	1970	89.5
92	15.0	732	.743	101.8	63.2	.0236	2115	87.4
93	15.0	727	.743	101.8	33.5	.0125	1530	90.0
94	15.0	728	.743	101.8	29.8	.0111	1435	88.5
95	15.0	729	.963	131.9	44.0	.0127	1565	92.5
96	15.0	729	.963	131.9	49.9	.0144	1665	92.3
97	15.0	729	.963	131.9	56.3	.0162	1770	92.2
98	15.0	729	.963	131.9	62.7	.0181	1860	90.6
99	15.0	729	.963	131.9	65.6	.0189	1860	87.0
100	15.0	729	.962	131.8	37.3	.0108	1430	90.1
101	15.0	729	.962	131.8	35.1	.0101	1390	90.5

TABLE II - PERFORMANCE DATA OF J33 COMBUSTOR - Continued

[Fuel nozzle capacity, 40 gal/hr]

Run	Combustor-inlet total pressure (in. Hg abs)	Combustor-inlet temperature (°R)	Air flow (lb/sec)	Combustor reference velocity (ft/sec)	Fuel flow (lb/hr)	Fuel-air ratio	Mean combustor-outlet temperature (°R)	Combustion efficiency (percent)
Standard combustor with small dams $4\frac{5}{8}$ inches from nozzle tip								
102	15.0	726	0.574	78.6	35.1	0.0170	1740	85.7
103	15.0	726	.574	78.6	31.3	.0152	1630	84.4
104	15.0	726	.575	78.8	27.5	.0133	1500	81.6
105	15.0	726	.575	78.8	26.0	.0126	1450	80.2
106	15.0	726	.575	78.8	24.0	.0116	1380	78.2
107	15.0	726	.575	78.8	22.1	.0107	1280	71.3
108	15.0	725	.575	78.8	40.8	.0197	1915	88.2
109	15.0	726	.575	78.8	49.1	.0237	2120	87.7
110	15.0	727	.575	78.8	54.5	.0263	2230	86.3
111	15.0	726	.575	78.8	58.4	.0282	2320	86.2
112	15.0	728	.575	78.8	61.0	.0295	2385	86.2
113	15.0	727	.575	78.8	65.3	.0315	2465	85.4
114	15.0	726	.740	101.4	33.3	.0125	1535	90.7
115	15.0	726	.740	101.4	39.4	.0148	1680	91.7
116	15.0	727	.740	101.4	46.3	.0174	1815	90.3
117	15.0	727	.740	101.4	56.3	.0211	2015	89.9
118	15.0	727	.740	101.4	62.6	.0235	2120	88.4
119	15.0	727	.740	101.4	72.4	.0272	2305	88.2
120	15.0	727	.740	101.4	78.2	.0294	2355	84.8
121	15.0	727	.740	101.4	33.3	.0125	1555	93.0
122	15.0	728	.963	131.9	46.3	.0134	1610	92.9
123	15.0	728	.963	131.9	53.6	.0155	1730	92.4
124	15.0	728	.963	131.9	61.8	.0178	1850	91.3
125	15.0	728	.963	131.9	68.3	.0197	1960	91.6
126	15.0	726	.963	131.9	75.5	.0218	2040	89.1
127	15.0	727	.963	131.9	43.6	.0126	1560	92.9
128	15.0	727	.963	131.9	36.3	.0105	1420	91.4
Standard combustor with small dams $5\frac{5}{8}$ inches from nozzle tip								
129	15.0	726	0.574	78.6	34.3	.0166	1710	84.9
130	15.0	727	.574	78.6	41.2	.0200	1915	86.9
131	15.0	726	.574	78.6	47.2	.0228	2065	87.1
132	15.0	727	.574	78.6	54.7	.0265	2225	85.4
133	15.0	727	.574	78.6	60.3	.0292	2335	84.3
134	15.0	727	.574	78.6	62.9	.0304	2400	84.7
135	15.0	726	.574	78.6	34.1	.0165	1735	87.7
136	15.0	727	.574	78.6	29.8	.0144	1580	83.7
137	15.0	727	.574	78.6	27.6	.0134	1500	81.0
138	15.0	727	.574	78.6	24.0	.0116	1360	75.7
139	15.0	728	.968	132.6	41.7	.0120	1480	87.5
140	15.0	727	.968	132.6	37.7	.0108	1390	85.0
141	15.0	728	.966	132.4	33.8	.0097	1300	80.8
142	15.0	728	.968	132.6	47.7	.0137	1600	89.9
143	15.0	728	.966	132.4	53.6	.0154	1710	91.0
144	15.0	728	.966	132.4	59.5	.0171	1810	91.2
145	15.0	728	.966	132.4	65.8	.0189	1910	91.1
146	15.0	728	.966	132.4	73.4	.0211	2005	89.1
147	15.0	728	.966	132.4	78.8	.0227	2030	84.9

TABLE II - PERFORMANCE DATA OF J33 COMBUSTOR - Continued

[Fuel nozzle capacity, 40 gal/hr for runs 148 to 161
Fuel nozzle capacity, 15.3 gal/hr for runs 162 to 195]

Run	Combustor-inlet total pressure (in. Hg abs)	Combustor-inlet temperature (°R)	Air flow (lb/sec)	Combustor reference velocity (ft/sec)	Fuel flow (lb/hr)	Fuel-air ratio	Mean combustor-outlet temperature (°R)	Combustion efficiency (percent)
Standard combustor with large dams $4\frac{5}{8}$ inches from nozzle tip								
148	15.0	729	0.569	78.0	33.8	0.0165	1725	86.5
149	15.0	728	.569	78.0	42.4	.0207	1950	86.6
150	15.0	729	.569	78.0	49.3	.0241	2125	86.5
151	15.0	729	.569	78.0	56.8	.0277	2285	85.4
152	15.0	729	.569	78.0	59.5	.0291	2340	84.7
153	15.0	729	.569	78.0	29.6	.0145	1590	84.0
154	15.0	728	.569	78.0	26.1	.0127	1480	82.8
155	15.0	730	.961	131.6	38.4	.0111	1460	91.5
156	15.0	730	.961	131.6	45.4	.0131	1580	91.3
157	15.0	729	.961	131.6	53.4	.0154	1720	91.9
158	15.0	730	.961	131.6	61.0	.0176	1835	90.8
159	15.0	730	.961	131.6	64.5	.0186	1885	90.3
160	15.0	730	.961	131.6	36.7	.0106	1420	90.2
161	15.0	731	.961	131.6	33.3	.0096	1350	88.7
Standard combustor with upstream louvers closed								
162	15.0	727	0.573	78.5	38.5	.0187	1525	60.9
163	15.0	728	.573	78.5	44.9	.0218	1695	64.4
164	15.0	728	.573	78.5	47.7	.0231	1830	70.0
165	15.0	728	.573	78.5	50.4	.0244	1940	73.5
166	15.0	728	.572	78.3	54.5	.0265	2090	77.1
167	15.0	728	.574	78.6	58.8	.0285	2215	79.2
168	15.0	729	.574	78.6	61.6	.0298	2300	80.6
169	15.0	727	.576	78.9	64.5	.0311	2370	81.3
170	15.0	728	.576	78.9	68.6	.0331	2465	81.6
171	15.0	728	.577	79.0	38.7	.0186	1460	55.9
172	15.0	727	.577	79.0	36.7	.0177	1380	52.1
173	15.0	726	.577	79.0	34.3	.0165	1290	47.8
174	15.0	726	.575	78.8	31.7	.0153	1210	44.0
175	15.0	727	.577	79.0	28.2	.0136	1110	38.9
176	15.0	726	.575	78.8	38.9	.0188	1465	55.9
177	15.0	726	.577	79.0	44.7	.0215	1700	65.7
178	15.0	726	.741	101.6	41.9	.0157	1355	56.1
179	15.0	726	.741	101.6	47.8	.0179	1515	62.7
180	15.0	726	.740	101.4	53.8	.0202	1690	68.9
181	15.0	726	.740	101.4	59.5	.0223	1855	74.2
182	15.0	726	.740	101.4	64.5	.0242	2000	78.2
183	15.0	726	.740	101.4	68.8	.0258	2110	80.4
184	15.0	726	.740	101.4	74.6	.0280	2240	82.1
185	15.0	727	.740	101.4	79.1	.0297	2360	84.3
186	15.0	727	.740	101.4	84.2	.0316	2460	84.9
187	15.0	727	.740	101.4	36.8	.0138	1235	51.0
188	15.0	727	.740	101.4	32.5	.0122	1140	46.6
189	15.0	728	.966	132.4	36.3	.0104	1165	57.5
190	15.0	728	.966	132.4	46.9	.0135	1325	61.5
191	15.0	728	.966	132.4	57.9	.0166	1500	65.9
192	15.0	727	.966	132.4	67.3	.0194	1670	70.0
193	15.0	730	.967	132.5	77.4	.0222	1840	73.2
194	15.0	728	.966	132.4	85.7	.0246	2000	76.8
195	15.0	728	.966	132.4	88.3	.0254	2060	78.3

2705

TABLE II - PERFORMANCE DATA OF J33 COMBUSTOR - Continued

[Fuel nozzle capacity, 15.3 gal/hr for runs 196 to 219
Fuel nozzle capacity, 40 gal/hr for 220 runs to 255]

Run	Combustor-inlet total pressure (in. Hg abs)	Combustor-inlet temperature (°R)	Air flow (lb/sec)	Combustor reference velocity (ft/sec)	Fuel flow (lb/hr)	Fuel-air ratio	Mean combustor-outlet temperature (°R)	Combustion efficiency (percent)
Standard combustor with small dams $5\frac{5}{8}$ inches from nozzle tip								
196	15.0	728	0.574	78.6	42.4	0.0205	1685	67.4
197	15.0	728	.572	78.3	46.3	.0225	1910	77.3
198	15.0	728	.572	78.3	51.3	.0249	2085	81.4
199	15.0	728	.572	78.3	57.4	.0279	2255	83.1
200	15.0	728	.572	78.3	66.4	.0322	2480	84.5
201	15.0	728	.572	78.3	61.6	.0299	2375	84.6
202	15.0	728	.572	78.3	37.7	.0183	1510	60.8
203	15.0	727	.572	78.3	33.6	.0163	1305	49.7
204	15.0	727	.572	78.3	29.8	.0145	1155	40.9
205	15.0	728	.744	101.9	30.7	.0115	1095	43.7
206	15.0	728	.744	101.9	38.5	.0144	1315	56.8
207	15.0	729	.744	101.9	44.9	.0168	1525	67.2
208	15.0	728	.744	101.9	49.9	.0186	1715	76.4
209	15.0	728	.742	101.7	55.9	.0209	1920	83.6
210	15.0	729	.744	101.9	62.7	.0234	2090	86.6
211	15.0	729	.744	101.9	69.9	.0261	2240	87.5
212	15.0	729	.744	101.9	79.6	.0297	2410	87.0
213	15.0	729	.964	132.0	31.3	.0090	1145	62.8
214	15.0	729	.964	132.0	38.7	.0112	1275	67.2
215	15.0	729	.964	132.0	45.3	.0131	1425	74.2
216	15.0	729	.964	132.0	52.5	.0151	1590	80.8
217	15.0	729	.963	131.9	58.2	.0168	1720	84.6
218	15.0	726	.963	131.9	66.7	.0192	1845	84.7
219	15.0	730	.963	131.9	74.1	.0214	1945	83.4
Standard combustor coated with ceramic coating 1								
220	15.0	727	0.960	131.5	37.9	0.0110	1395	84.2
221	15.0	727	.962	131.8	46.7	.0135	1545	85.3
222	15.0	726	.960	131.5	55.1	.0159	1680	85.6
223	15.0	727	.960	131.5	62.6	.0181	1805	86.1
224	15.0	727	.962	131.8	69.5	.0201	1910	86.0
225	15.0	727	.962	131.8	76.9	.0222	2005	85.0
226	15.0	726	.962	131.8	85.0	.0245	2060	81.1
227	15.0	727	.742	101.7	33.1	.0124	1505	87.8
228	15.1	725	.742	101.7	38.7	.0145	1640	89.5
229	15.1	727	.742	101.7	46.3	.0173	1795	89.0
230	15.0	726	.742	101.7	51.7	.0194	1905	88.6
231	15.0	726	.742	101.7	59.8	.0224	2045	87.2
232	14.9	727	.742	101.7	66.4	.0249	2175	87.3
233	15.0	727	.742	101.7	70.8	.0265	2260	87.6
234	15.0	726	.742	101.7	29.1	.0109	1425	89.0
235	15.0	727	.575	78.8	31.1	.0150	1635	86.0
236	15.0	727	.576	78.9	36.3	.0175	1770	85.8
237	15.0	727	.576	78.9	40.8	.0197	1910	87.7
238	15.1	727	.576	78.9	47.2	.0228	2070	87.4
239	15.1	726	.576	78.9	54.5	.0263	2220	85.7
240	15.0	726	.576	78.9	55.8	.0269	2255	86.1
241	15.0	728	.576	78.9	35.3	.0170	1765	87.7
242	15.0	728	.576	78.9	31.1	.0150	1645	86.8
243	15.0	727	.576	78.9	27.3	.0132	1540	86.6
244	15.0	727	.576	78.9	23.1	.0111	1435	88.6
245	15.0	727	.576	78.9	20.6	.0099	1360	87.9
246	15.0	727	.575	78.8	18.7	.0090	1290	85.4
247	15.0	727	.576	78.9	14.0	.0068	1150	84.8
248	8.0	729	.394	101.1	27.6	.0195	1705	72.2
249	8.0	728	.394	101.0	30.1	.0213	1780	71.9
250	8.0	728	.394	101.0	30.8	.0218	1815	72.8
251	8.0	729	.394	101.0	32.1	.0227	1840	71.8
252	8.0	728	.394	101.1	33.3	.0235	1850	70.2
253	8.0	729	.394	101.0	25.6	.0181	1665	74.2
254	8.0	729	.394	101.0	23.2	.0165	1595	74.7
255	8.0	729	.394	101.1	19.5	.0138	1435	71.6

[redacted]

2705

TABLE II - PERFORMANCE DATA OF J33 COMBUSTOR - Continued

[Fuel-nozzle capacity, 40 gal/hr]

Run	Combustor-inlet total pressure (in. Hg abs)	Combustor-inlet temperature (°R)	Air flow (lb/sec)	Combustor reference velocity (ft/sec)	Fuel flow (lb/hr)	Fuel-air ratio	Mean combustor-outlet temperature (°R)	Combustion efficiency (percent)
Standard combustor coated with ceramic coating 2								
256	15.0	730	0.568	77.8	41.0	0.0200	1800	77.7
257	15.0	726	.568	77.8	45.8	.0224	1980	82.6
258	15.0	726	.568	77.8	51.3	.0251	2135	84.1
259	15.0	726	.568	77.8	55.0	.0269	2225	84.3
260	15.0	726	.568	77.8	55.7	.0272	2250	84.9
261	15.0	726	.568	77.8	41.3	.0202	1860	81.8
262	15.0	726	.568	77.8	36.3	.0178	1665	75.6
263	15.0	726	.568	77.8	30.8	.0151	1400	62.6
264	15.0	726	.568	77.8	33.8	.0165	1550	70.9
265	15.0	726	.568	77.8	28.3	.0138	1300	57.8
266	15.0	726	.568	77.8	24.4	.0119	1180	52.4
267	15.0	726	.568	77.8	22.1	.0108	1120	49.9
268	15.0	726	.568	77.8	17.7	.0087	1020	45.8
269	15.0	727	.742	101.7	39.2	.0147	1480	72.1
270	15.0	726	.742	101.7	45.4	.0170	1660	78.5
271	15.0	726	.742	101.7	50.2	.0188	1810	83.5
272	15.0	727	.742	101.7	59.3	.0222	2030	86.8
273	15.0	727	.742	101.7	67.7	.0253	2195	87.3
274	15.0	727	.742	101.7	72.8	.0273	2290	87.0
275	15.0	728	.742	101.7	36.5	.0137	1420	70.6
276	15.0	728	.742	101.7	32.5	.0122	1300	64.9
277	15.0	727	.742	101.7	28.8	.0108	1210	61.4
278	15.0	728	.961	131.6	42.6	.0123	1365	71.9
279	15.0	728	.962	131.8	51.8	.0150	1520	74.5
280	15.0	728	.962	131.8	57.4	.0166	1630	77.5
281	15.0	728	.962	131.8	65.3	.0189	1785	80.9
282	15.0	728	.962	131.8	73.3	.0212	1915	82.1
283	15.0	728	.962	131.8	77.8	.0225	1985	82.5
284	15.0	728	.962	131.8	37.1	.0107	1260	68.4
285	15.0	728	.962	131.8	32.3	.0093	1195	68.5
Standard combustor coated with ceramic coating 3								
286	15.0	729	0.575	78.8	42.8	0.0207	1895	82.4
287	15.0	728	.576	78.9	47.6	.0230	2030	83.9
288	15.0	729	.576	78.9	55.7	.0269	2255	85.9
289	15.0	728	.577	79.0	52.0	.0250	2150	85.3
290	15.0	728	.577	79.0	57.7	.0278	2305	86.3
291	15.0	727	.577	79.0	59.9	.0288	2355	86.5
292	15.0	727	.577	79.0	61.8	.0298	2390	85.7
293	15.0	727	.577	79.0	37.4	.0180	1730	80.2
294	15.0	727	.577	79.0	33.3	.0160	1590	76.6
295	15.0	727	.577	79.0	29.9	.0144	1475	73.0
296	15.0	727	.577	79.0	27.1	.0130	1375	69.4
297	15.0	727	.577	79.0	24.9	.0120	1330	69.6
298	15.0	728	.747	102.3	41.9	.0156	1640	83.2
299	15.0	728	.747	102.3	37.7	.0140	1530	80.6
300	15.0	727	.744	101.9	34.6	.0129	1450	78.3
301	15.0	727	.749	102.6	30.8	.0114	1365	77.5
302	15.0	728	.749	102.6	27.1	.0101	1250	70.9
303	15.0	728	.748	102.5	49.1	.0182	1805	85.6
304	15.0	728	.746	102.2	54.1	.0201	1925	87.1
305	15.0	727	.746	102.2	60.6	.0226	2065	87.8
306	15.0	727	.746	102.2	66.7	.0248	2190	88.6
307	15.0	727	.746	102.2	71.7	.0267	2280	88.2
308	15.0	728	.965	132.2	44.7	.0129	1485	82.1
309	15.0	727	.965	132.2	49.5	.0142	1580	84.9
310	15.0	728	.962	131.8	56.6	.0163	1705	85.8
311	15.0	728	.962	131.8	68.2	.0197	1885	85.6
312	15.0	722	.962	131.8	75.1	.0217	1980	85.4
313	15.0	728	.962	131.8	85.7	.0247	2055	80.1
314	15.0	728	.962	131.8	39.7	.0115	1365	76.8
315	15.0	728	.962	131.8	37.3	.0108	1320	75.6
316	8.0	725	.398	102.2	31.8	.0222	1760	67.9
317	8.0	725	.398	102.2	29.3	.0204	1660	66.1
318	8.0	725	.398	102.2	27.1	.0189	1560	63.1
319	8.0	726	.398	102.2	24.1	.0168	1435	59.5

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2705

TABLE II - PERFORMANCE DATA OF J33 COMBUSTOR - Continued

[Fuel nozzle capacity, 40 gal/hr]

Run	Combustor-inlet total pressure (in. Hg abs)	Combustor-inlet temperature (°R)	Air flow (lb/sec)	Combustor reference velocity (ft/sec)	Fuel flow (lb/hr)	Fuel-air ratio	Mean combustor-outlet temperature (°R)	Combustion efficiency (percent)
Standard combustor after removal of ceramic coating 2								
320	8.0	731	0.400	102.7	32.6	0.0226	1750	65.8
321	8.0	730	.400	102.7	34.6	.0240	1790	64.8
322	8.0	732	.400	102.7	37.6	.0261	1840	62.8
323	8.0	729	.396	101.7	30.2	.0212	1640	62.1
324	8.0	731	.395	101.5	26.2	.0187	1535	61.4
325	8.0	731	.394	101.1	24.7	.0174	1440	57.7
326	8.0	731	.396	101.7	21.4	.0150	1335	56.3
327	8.0	732	.396	101.7	18.7	.0131	1185	47.8
328	8.0	732	.400	102.7	36.7	.0255	1810	62.4
329	15.0	729	.566	77.6	44.7	.0219	1880	77.1
330	15.0	729	.566	77.6	49.5	.0243	2025	79.3
331	15.0	729	.566	77.6	58.2	.0286	2280	82.6
332	15.0	730	.566	77.6	53.3	.0262	2150	81.5
333	15.0	729	.568	77.8	60.4	.0295	2330	83.1
334	15.0	729	.568	77.8	62.3	.0305	2380	83.3
335	15.0	730	.566	77.6	65.6	.0322	2445	82.6
336	15.0	730	.567	77.7	45.6	.0223	1935	79.6
337	15.0	730	.567	77.7	38.1	.0187	1670	72.3
338	15.0	730	.567	77.7	33.6	.0165	1520	67.8
339	15.0	730	.739	101.2	38.7	.0145	1480	72.7
340	15.0	729	.739	101.2	52.3	.0197	1810	79.7
341	15.0	729	.739	101.2	64.3	.0242	2070	82.6
342	15.0	724	.739	101.2	72.7	.0273	2245	84.4
343	15.0	732	.965	132.2	50.6	.0146	1500	74.1
344	15.0	731	.965	132.2	62.1	.0179	1700	77.8
345	15.0	731	.967	132.5	73.3	.0211	1900	81.2
346	15.0	731	.967	132.5	81.3	.0234	2020	81.7
347	15.0	732	.967	132.5	89.1	.0256	2090	79.4
348	15.0	731	.967	132.5	43.3	.0124	1380	72.8
349	15.0	731	.967	132.5	38.9	.0112	1305	70.8
350	15.0	730	.571	78.2	37.6	.0183	1670	73.8
351	15.0	730	.571	78.2	30.6	.0149	1450	67.9
352	15.0	728	.572	78.3	26.3	.0128	1290	60.8
353	15.0	730	.569	78.0	42.4	.0207	1820	76.7
354	15.0	729	.569	78.0	49.1	.0240	2020	79.9
355	15.0	729	.570	78.0	57.0	.0278	2270	84.2
356	15.0	728	.570	78.0	58.8	.0287	2315	84.4
357	15.0	729	.737	101.0	53.6	.0202	1880	83.2
358	15.0	729	.737	101.0	60.2	.0227	2035	85.3
359	15.0	729	.739	101.2	68.7	.0258	2235	88.1
360	15.0	729	.739	101.2	71.9	.0270	2295	88.1
361	15.0	728	.739	101.2	72.8	.0274	2310	87.8
362	15.0	727	.739	101.2	47.7	.0179	1740	81.5
363	15.0	729	.739	101.2	72.6	.0160	1610	78.3
364	15.0	726	.740	101.4	38.8	.0146	1510	75.6
365	15.0	730	.740	101.4	35.3	.0133	1430	73.6
366	15.0	730	.967	132.5	42.6	.0122	1405	77.0
367	15.0	729	.965	132.2	39.9	.0115	1360	76.0
368	15.0	730	.965	132.2	50.2	.0145	1535	78.3
369	15.0	729	.967	132.5	56.6	.0163	1635	79.2
370	15.0	730	.967	132.5	62.1	.0178	1735	81.2
371	15.0	730	.967	132.5	69.3	.0199	1850	82.0
372	15.0	730	.969	132.7	74.3	.0213	1925	82.3
373	15.0	730	.967	132.5	80.4	.0231	2010	82.1
374	15.0	729	.969	132.7	87.9	.0252	2080	80.1
375	8.0	729	.400	102.7	31.6	.0219	1710	65.1
376	8.0	727	.400	102.7	32.5	.0226	1760	66.7
377	8.0	727	.400	102.7	34.3	.0238	1785	65.2
378	8.0	728	.400	102.7	30.0	.0208	1650	64.0
379	8.0	728	.400	102.7	25.5	.0177	1510	62.7
380	8.0	728	.400	102.7	22.9	.0159	1410	60.3
381	8.0	728	.397	101.9	20.0	.0140	1260	52.8

2705

TABLE II - PERFORMANCE DATA OF J33 COMBUSTOR - Concluded

[Fuel nozzle capacity, 40 gal/hr]

Run	Combustor-inlet total pressure (in. Hg abs)	Combustor-inlet temperature (°R)	Air flow (lb/sec)	Combustor reference velocity (ft/sec)	Fuel flow (lb/hr)	Fuel-air ratio	Mean combustor-outlet temperature (°R)	Combustion efficiency (percent)
Standard combustor with ceramic coating 1 and small dams $5\frac{5}{8}$ inches from nozzle tip								
382	15.0	730	0.582	79.7	35.7	0.0170	1740	85.3
383	15.0	730	.579	79.3	24.9	.0119	1460	85.5
384	15.0	730	.579	79.3	46.7	.0224	2045	86.9
385	15.0	729	.579	79.3	53.6	.0257	2200	86.2
386	15.0	729	.579	79.3	60.6	.0291	2335	84.4
387	15.0	732	.968	132.6	43.1	.0124	1465	82.6
388	15.0	731	.968	132.6	55.3	.0159	1660	83.3
389	15.0	731	.965	132.2	66.7	.0192	1830	83.1
390	15.0	731	.958	131.2	75.1	.0218	1940	81.6
391	15.0	728	.573	78.5	31.3	.0152	1660	87.3
392	15.0	728	.570	78.0	22.2	.0108	1400	86.2
393	15.0	728	.573	78.5	36.7	.0178	1790	86.1
394	15.0	728	.573	78.5	44.0	.0213	1985	86.9
395	15.0	728	.570	78.0	52.7	.0257	2200	86.2
396	15.0	731	.573	78.5	55.9	.0271	2250	85.1
397	15.0	730	.744	101.9	51.2	.0191	1925	91.3
398	15.0	729	.741	101.6	58.6	.0220	2060	89.6
399	15.0	729	.741	101.6	64.7	.0243	2150	87.5
400	15.0	728	.741	101.6	44.4	.0166	1780	91.1
401	15.0	729	.740	101.4	36.3	.0136	1590	89.3
402	15.0	729	.740	101.4	29.8	.0112	1435	87.6
403	15.0	730	.964	132.0	42.8	.0123	1520	90.0
404	15.0	730	.962	131.8	37.1	.0107	1405	87.4
405	15.0	730	.962	131.8	35.3	.0102	1365	85.9
406	15.0	730	.961	131.6	33.3	.0096	1325	85.0
407	15.0	730	.961	131.6	50.9	.0147	1680	92.0
408	15.0	730	.964	132.0	59.5	.0171	1805	90.7
409	15.0	728	.964	132.0	62.8	.0181	1845	89.4

TABLE III - PERFORMANCE DATA OF J47 COMBUSTOR

[Duplex fuel nozzle]

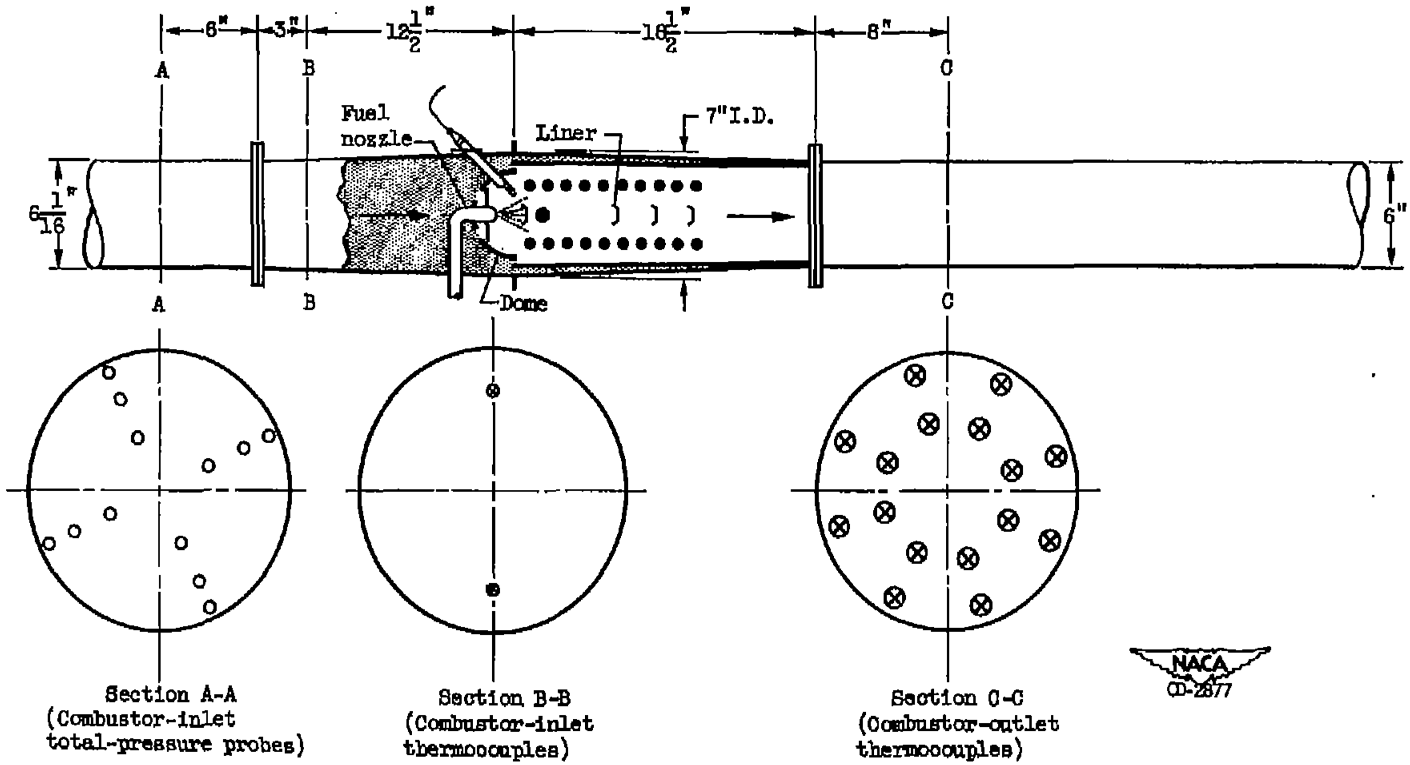
Run	Combustor-inlet total pressure (in. Hg abs)	Combustor-inlet temperature (°R)	Air flow (lb/sec)	Combustor reference velocity (ft/sec)	Fuel flow (lb/hr)	Fuel-air ratio	Mean combustor-outlet temperature (°R)	Combustion efficiency (percent)
Standard combustor								
1	8.0	724	0.716	101.8	38.3	0.0149	1455	69.1
2	8.0	724	.716	101.8	35.8	.0139	1415	69.6
3	8.0	727	.716	102.2	29.8	.0116	1315	70.3
4	8.0	725	.716	101.9	22.3	.0086	1090	57.2
5	8.0	725	.716	101.9	20.5	.0080	1035	52.6
6	8.0	722	.716	101.5	47.0	.0182	1635	71.7
7	8.0	732	.716	102.9	56.7	.0220	1735	66.4
8	8.0	728	.716	102.4	60.2	.0234	1775	65.6
9	8.0	724	.716	101.8	65.7	.0255	1805	62.5
10	15.0	728	1.030	78.4	38.0	.0102	1285	74.7
11	15.0	737	1.026	79.1	43.0	.0116	1400	79.2
12	15.0	729	1.024	78.1	52.3	.0142	1570	83.6
13	15.0	726	1.028	78.0	63.5	.0172	1790	89.3
14	15.0	725	1.024	77.7	72.9	.0198	1910	87.5
15	15.0	726	1.024	77.7	84.6	.0230	2090	88.4
16	15.0	725	1.024	77.7	103.0	.0279	2275	84.4
17	15.0	726	1.018	77.4	104.6	.0285	2295	83.9
18	15.0	727	1.024	77.9	109.3	.0296	2340	83.4
19	15.0	724	1.344	101.9	48.2	.0100	1305	80.2
20	15.0	726	1.345	102.2	47.0	.0097	1310	82.7
21	15.0	734	1.340	103.0	53.9	.0112	1410	84.0
22	15.0	725	1.343	101.9	65.0	.0134	1565	88.0
23	15.0	736	1.342	103.3	76.9	.0159	1735	89.9
24	15.0	723	1.336	101.2	100.1	.0208	1910	83.5
25	15.0	728	1.342	102.4	104.8	.0217	1950	82.9
26	15.0	726	1.742	132.5	42.3	.0067	1130	80.9
27	15.0	726	1.743	132.6	53.8	.0086	1250	83.4
28	15.0	726	1.742	132.5	71.0	.0113	1400	82.6
29	15.0	726	1.742	132.5	89.5	.0143	1555	82.0
30	15.0	726	1.742	132.5	102.4	.0163	1640	79.8
31	15.0	725	1.741	132.1	121.2	.0194	1750	76.6
32	15.0	727	1.746	132.9	136.3	.0217	1805	72.6

2705

TABLE III - PERFORMANCE DATA OF J47 COMBUSTOR - Concluded

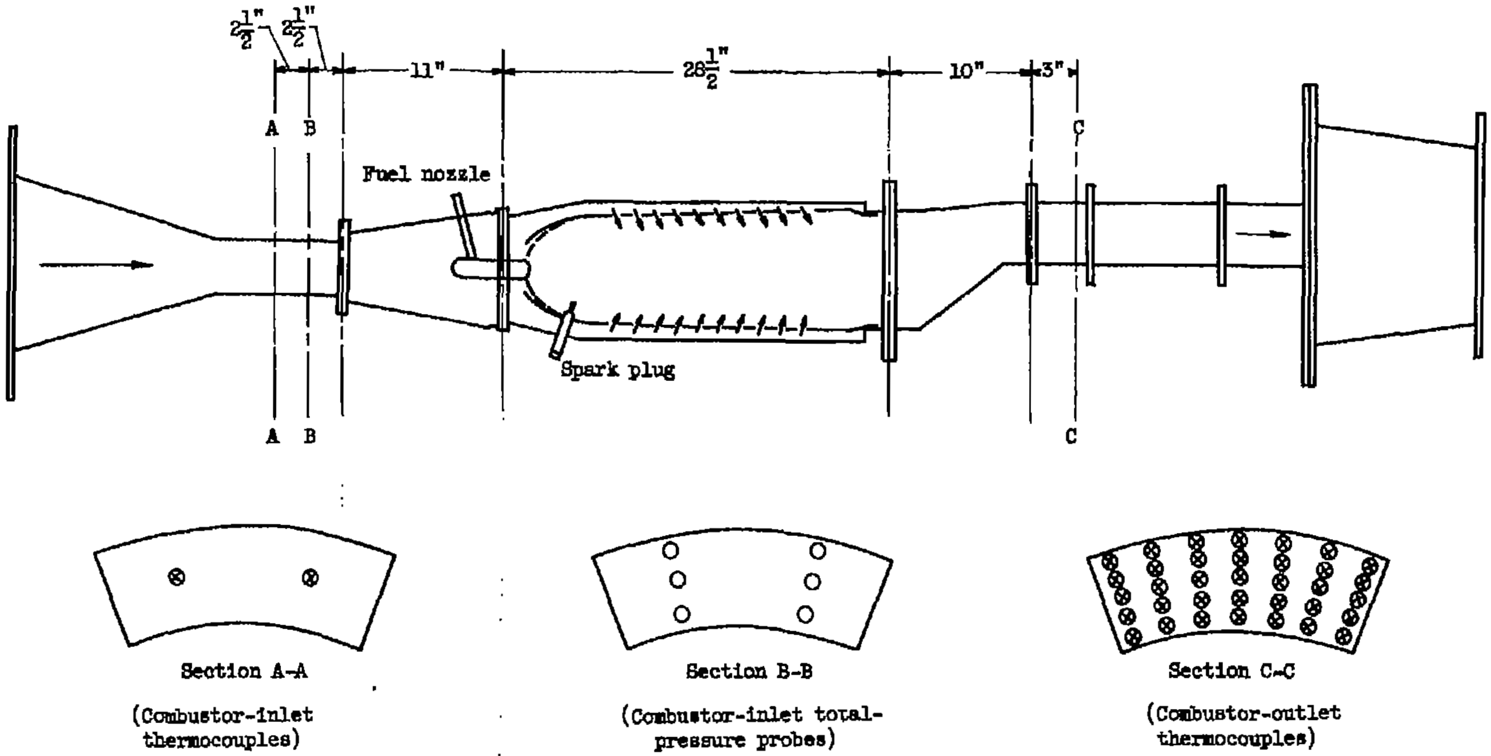
[Duplex fuel nozzle]

Run	Combustor-inlet total pressure (in. Hg abs)	Combustor-inlet temperature (°R)	Air flow (lb/sec)	Combustor reference velocity (ft/sec)	Fuel flow (lb/hr)	Fuel-air ratio	Mean combustor-outlet temperature (°R)	Combustion efficiency (percent)
Standard combustor coated with ceramic coating 1								
33	8.0	734	0.716	103.1	45.0	0.0175	1640	74.2
34	8.0	724	.716	101.8	54.8	.0213	1745	69.7
35	8.0	734	.716	103.1	59.5	.0231	1820	69.0
36	8.0	726	.716	102.1	60.9	.0236	1870	71.3
37	8.0	734	.716	103.1	45.2	.0175	1660	75.7
38	8.0	732	.716	102.9	38.3	.0149	1520	74.8
39	8.0	736	.716	103.5	33.4	.0130	1425	74.2
40	8.0	733	.717	103.1	28.5	.0110	1330	74.8
41	8.0	722	.716	101.5	23.9	.0093	1185	68.0
42	8.0	746	.716	104.9	23.9	.0093	1040	43.1
43	8.0	724	.717	102.0	24.4	.0094	1160	62.8
44	8.0	725	.717	102.1	34.0	.0132	1430	74.8
45	8.0	724	.712	101.4	48.5	.0189	1715	75.6
46	8.0	724	.712	101.4	57.5	.0224	1845	73.3
47	8.0	724	.712	101.4	59.5	.0232	1870	72.6
48	15.0	732	1.028	78.7	63.5	.0172	1780	88.0
49	15.0	720	1.030	77.6	55.5	.0150	1660	89.2
50	15.0	732	1.031	78.9	47.9	.0129	1550	89.1
51	15.0	728	1.027	78.2	35.6	.0096	1325	85.2
52	15.0	725	1.027	77.9	26.0	.0070	1140	79.8
53	15.0	735	1.027	79.0	68.3	.0185	1825	85.5
54	15.0	731	1.027	78.6	79.4	.0215	1980	85.8
55	15.0	725	1.027	77.9	92.0	.0249	2160	86.5
56	15.0	724	1.031	78.1	101.8	.0274	2260	85.0
57	15.0	724	1.035	78.4	106.1	.0285	2300	84.3
58	15.0	723	1.026	77.7	113.0	.0306	2360	82.3
59	15.0	727	1.035	78.7	32.2	.0086	1240	81.0
60	15.0	726	1.035	78.6	40.9	.0110	1405	85.7
61	15.0	726	1.025	77.9	53.9	.0146	1625	87.2
62	15.0	727	1.025	78.0	64.8	.0176	1790	87.3
63	15.0	727	1.026	78.1	74.5	.0202	1925	86.8
64	15.0	728	1.025	78.1	84.0	.0228	2050	86.2
65	15.0	728	1.025	78.1	100.5	.0272	2260	85.3
66	15.0	729	1.026	78.3	112.0	.0303	2350	82.1
67	15.0	724	1.335	101.1	47.0	.0098	1335	86.0
68	15.0	734	1.334	102.5	53.6	.0112	1430	86.7
69	15.0	734	1.334	102.5	64.8	.0135	1580	88.5
70	15.0	730	1.336	102.1	77.2	.0160	1710	87.4
71	15.0	727	1.336	101.7	91.5	.0190	1860	86.6
72	15.0	727	1.336	101.7	100.4	.0209	1960	86.8
73	15.0	728	1.334	101.6	103.9	.0216	1995	86.3
74	15.0	728	1.334	101.6	106.5	.0222	2025	86.4
75	15.0	728	1.334	101.6	110.9	.0231	2060	85.7
76	15.0	728	1.334	101.6	118.1	.0246	2115	84.4
77	15.0	729	1.336	101.9	123.6	.0257	2150	83.1
78	15.0	729	1.334	101.7	39.2	.0082	1235	84.5
79	15.0	728	1.334	101.6	31.9	.0066	1120	79.6
80	15.0	724	1.742	132.0	67.9	.0108	1315	88.4
81	15.0	722	1.743	131.9	79.0	.0126	1510	87.6
82	15.0	728	1.742	132.7	95.5	.0152	1655	86.6
83	15.0	730	1.742	133.0	110.0	.0175	1750	83.7
84	15.0	730	1.742	133.0	122.0	.0194	1815	81.0
85	15.0	730	1.746	133.5	141.0	.0224	1860	73.9
86	15.0	730	1.745	133.4	52.9	.0084	1260	85.9



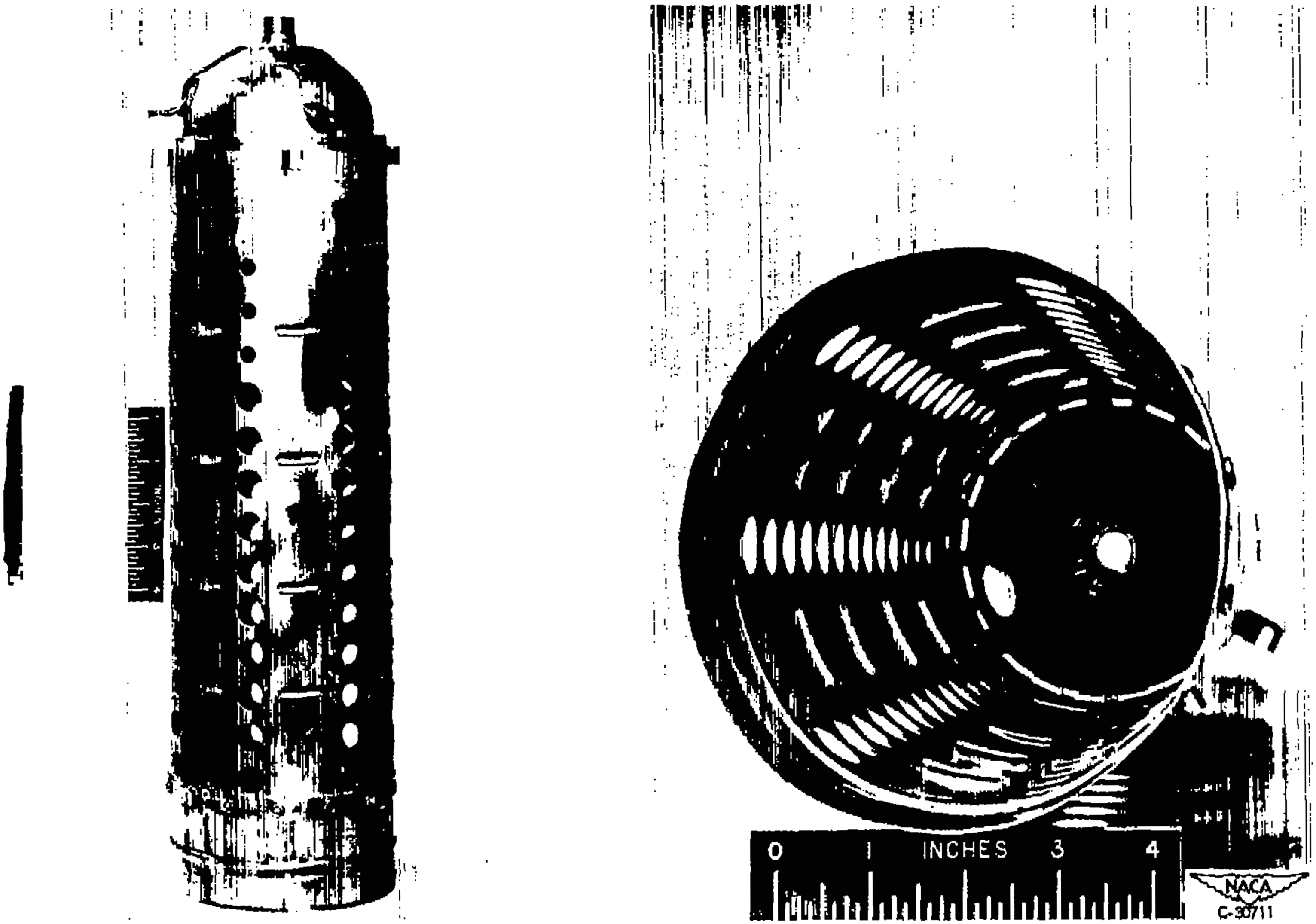
(a) J33 combustor.

Figure 1. - Cross section of single-combustor installation showing auxiliary ducting and location of temperature- and pressure-measuring instruments in instrumentation planes.



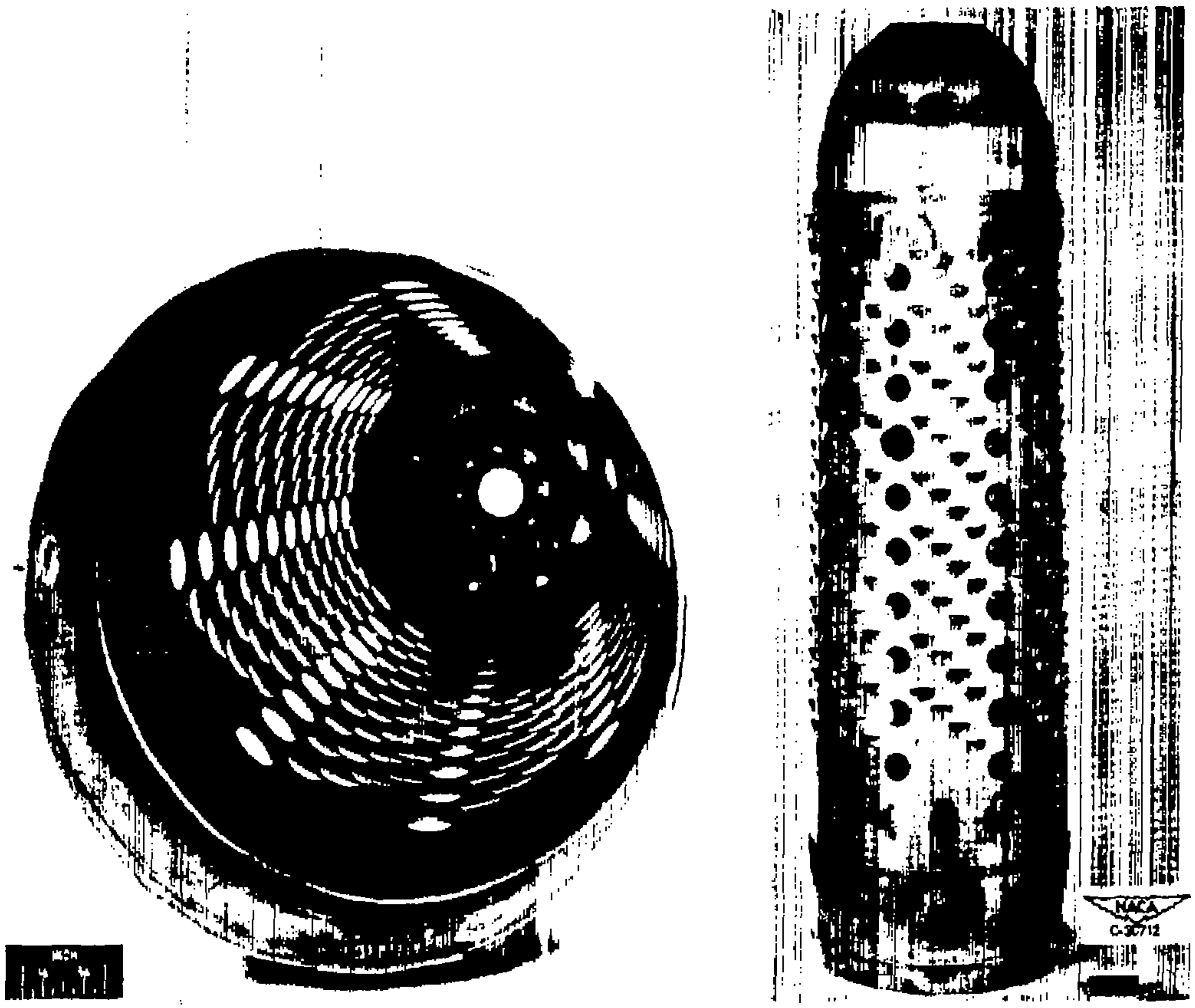
(b) J47 combustor.

Figure 1. - Concluded. Cross section of single-combustor installation showing auxiliary ducting and location of temperature- and pressure-measuring instruments in instrumentation planes.



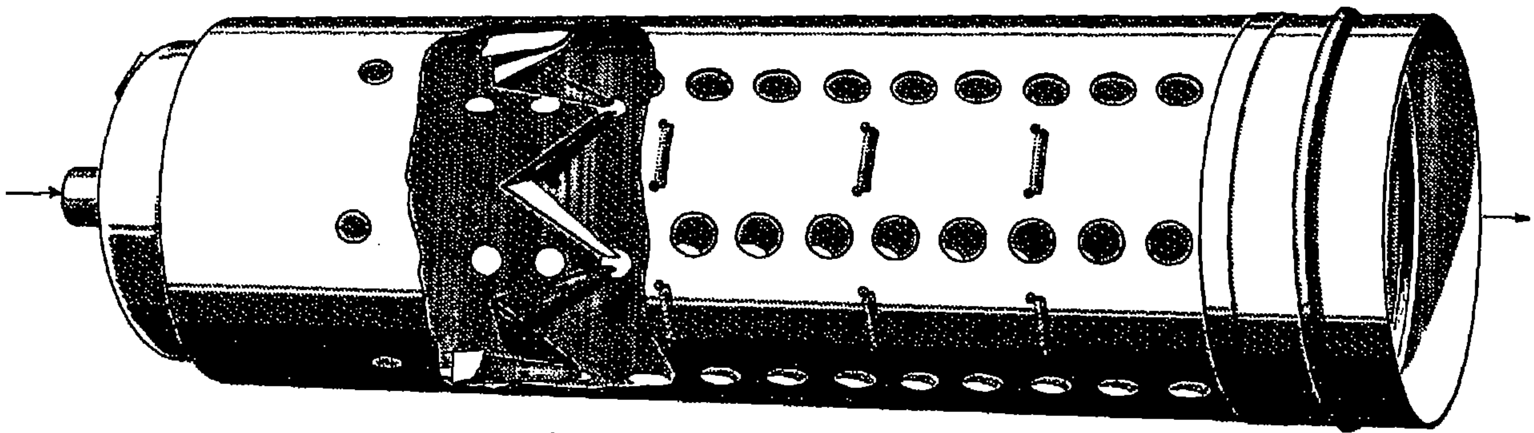
(a) J33 combustor.

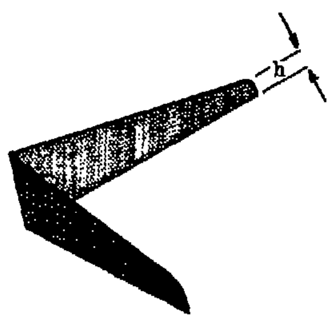
Figure 2. - Inner liner and dome of single combustors used in investigation.



(b) J47 combustor.

Figure 2. - Concluded. Inner liner and dome of single combustors used in investigation.





Dam height, h (in.)	Distance of dam vertex from nozzle tip (in.)
$\frac{1}{4}$	$3\frac{5}{8}$, $4\frac{5}{8}$, $5\frac{5}{8}$
$\frac{7}{16}$	$4\frac{5}{8}$

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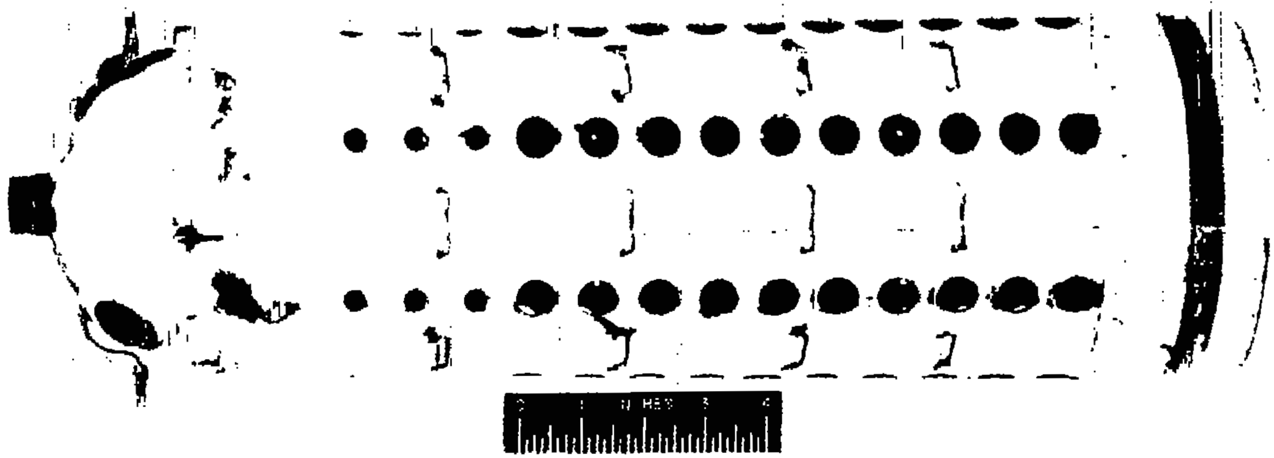
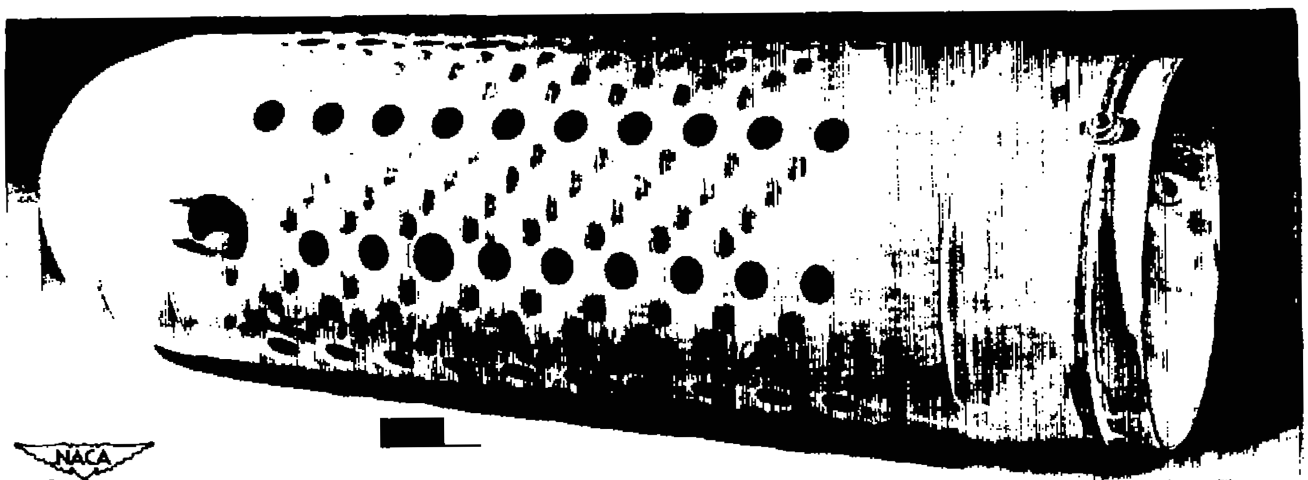
Figure 3. - Sketch of J33 liner showing installation of fuel dams.



(a) J33 liner.



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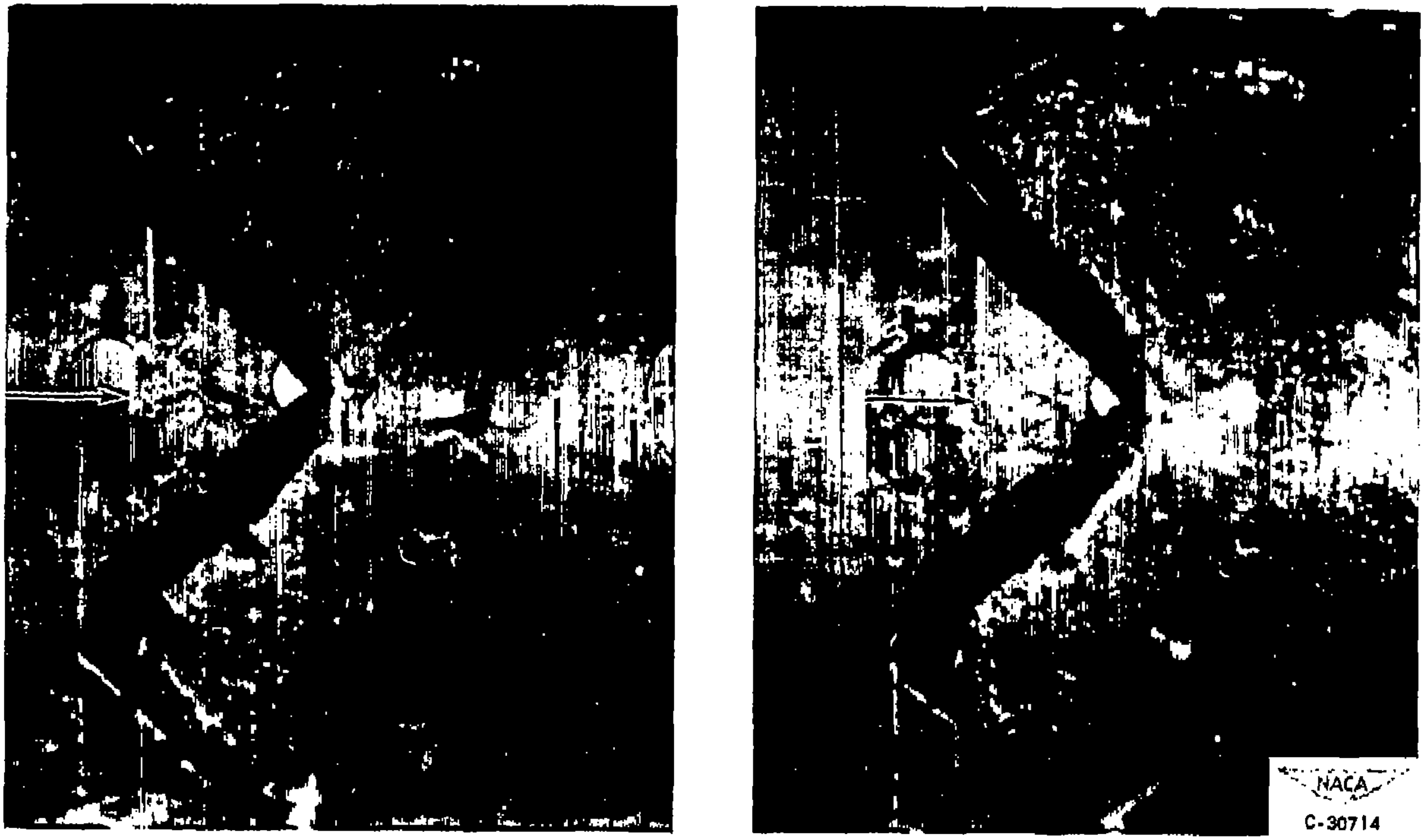
(b) J47 liner.

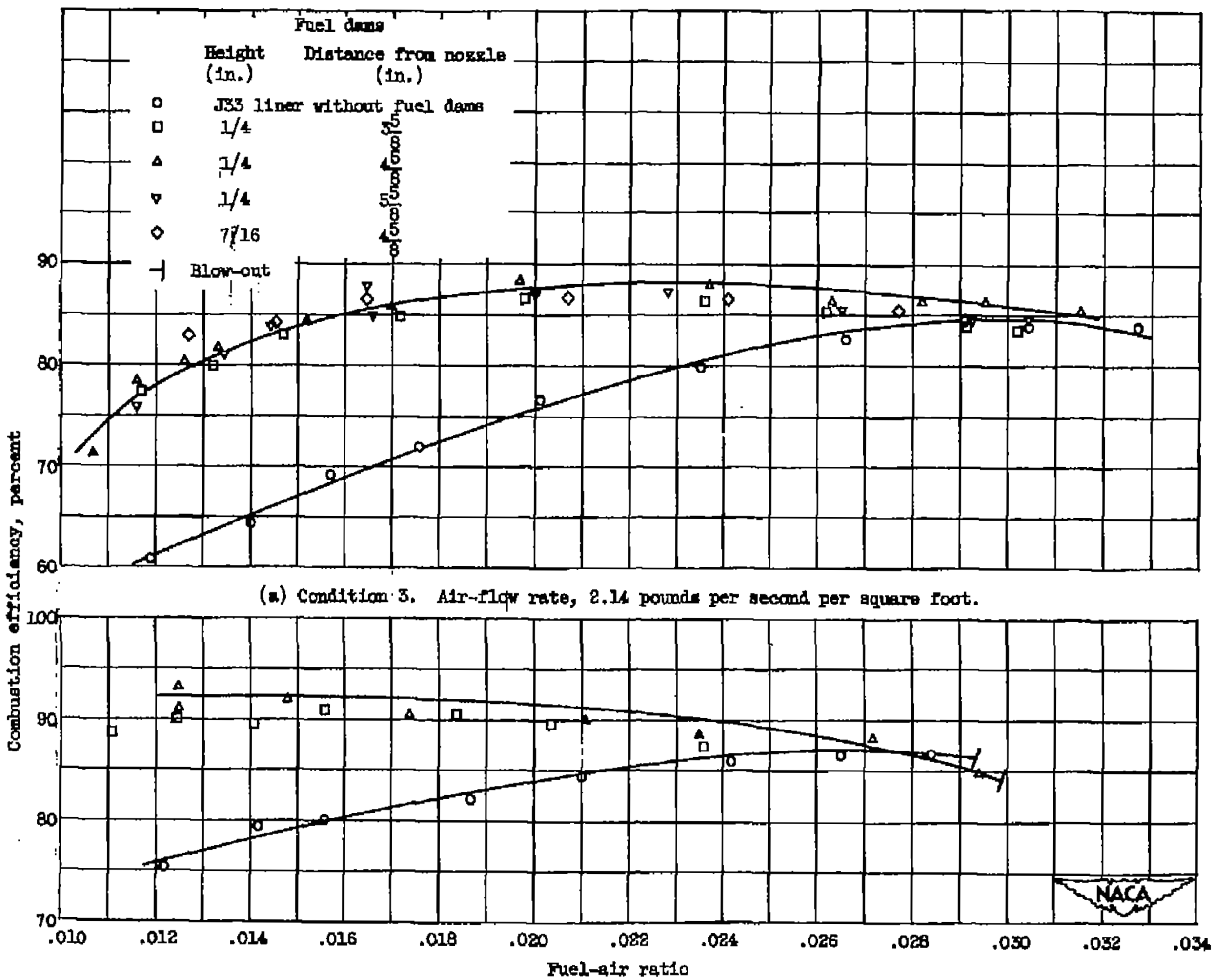
Figure 4. - Combustor liners coated with ceramic (1).



(a) Water-flow rate, 54 pounds per hour.

(b) Water-flow rate, 35 pounds per hour.

Figure 5. - Transparent combustor equipped with two fuel dams. Cold-flow inlet-air conditions: pressure, 15 inches of mercury absolute; temperature, 85° F; flow rate, 2.14 pounds per second per square foot. Fuel nozzle, 40 gallons per hour, 80° spray angle.



(a) Condition 3. Air-flow rate, 2.14 pounds per second per square foot.

(b) Condition 1. Air-flow rate, 2.78 pounds per second per square foot.

Figure 6. - Effect of fuel dams on combustion efficiency of J33 combustor using 40-gallon-per-hour 80°-spray-angle nozzle at various air-flow rates and fuel-air ratios. Inlet-air pressure, 15 inches of mercury absolute; inlet-air temperature, 268° F; fuel, MIL-F-5624A, grade JP-4.

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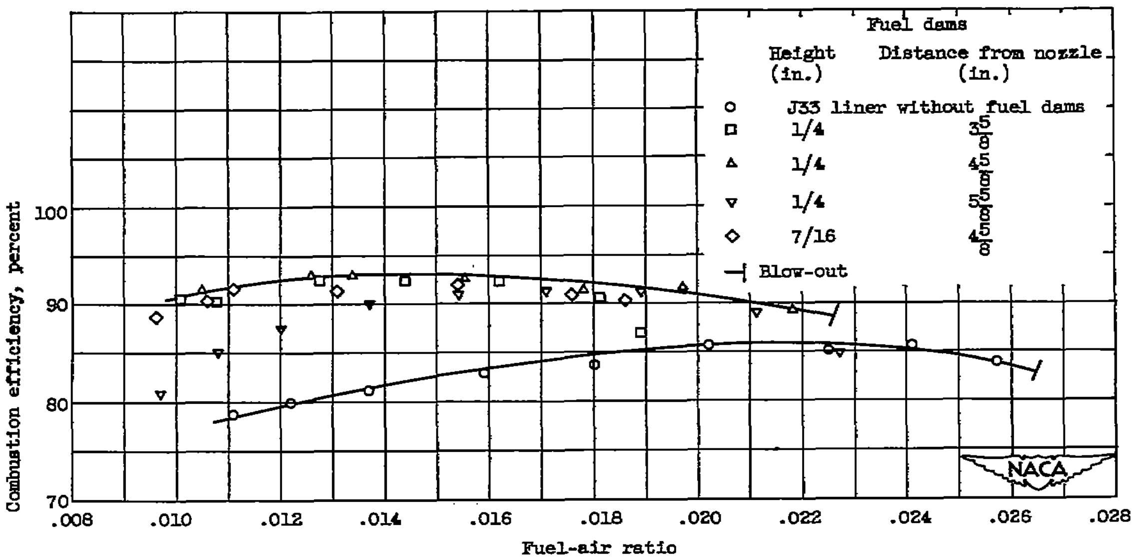

(c) Condition 4. Air-flow rate, 3.62 pounds per second per square foot.

Figure 6. - Concluded. Effect of fuel dams on combustion efficiency of J33 combustor using 40-gallon-per-hour 80°-spray-angle nozzle at various air-flow rates and fuel-air ratios. Inlet-air pressure, 15 inches of mercury absolute; inlet-air temperature, 268° F; fuel, MIL-F-5624A, grade JP-4.

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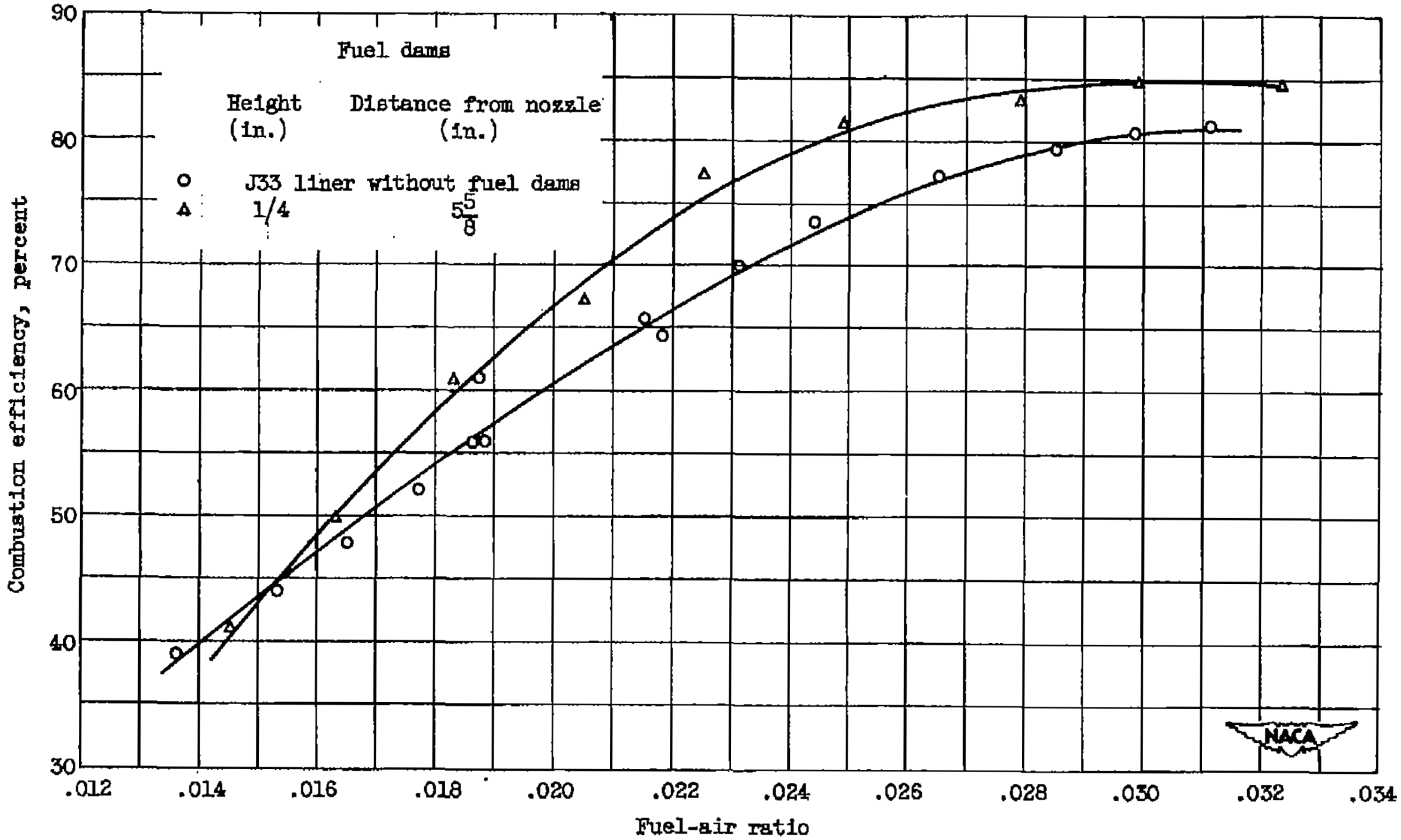

(a) Condition 3. Air-flow rate, 2.14 pounds per second per square foot.

Figure 7. - Effect of fuel dams on combustion efficiency of J33 combustor using 15.3-gallon-per-hour 30°-spray-angle nozzle at various air-flow rates and fuel-air ratios. Inlet-air pressure, 15 inches of mercury absolute; inlet-air temperature, 268° F; fuel, MIL-F-5624A, grade JP-4.

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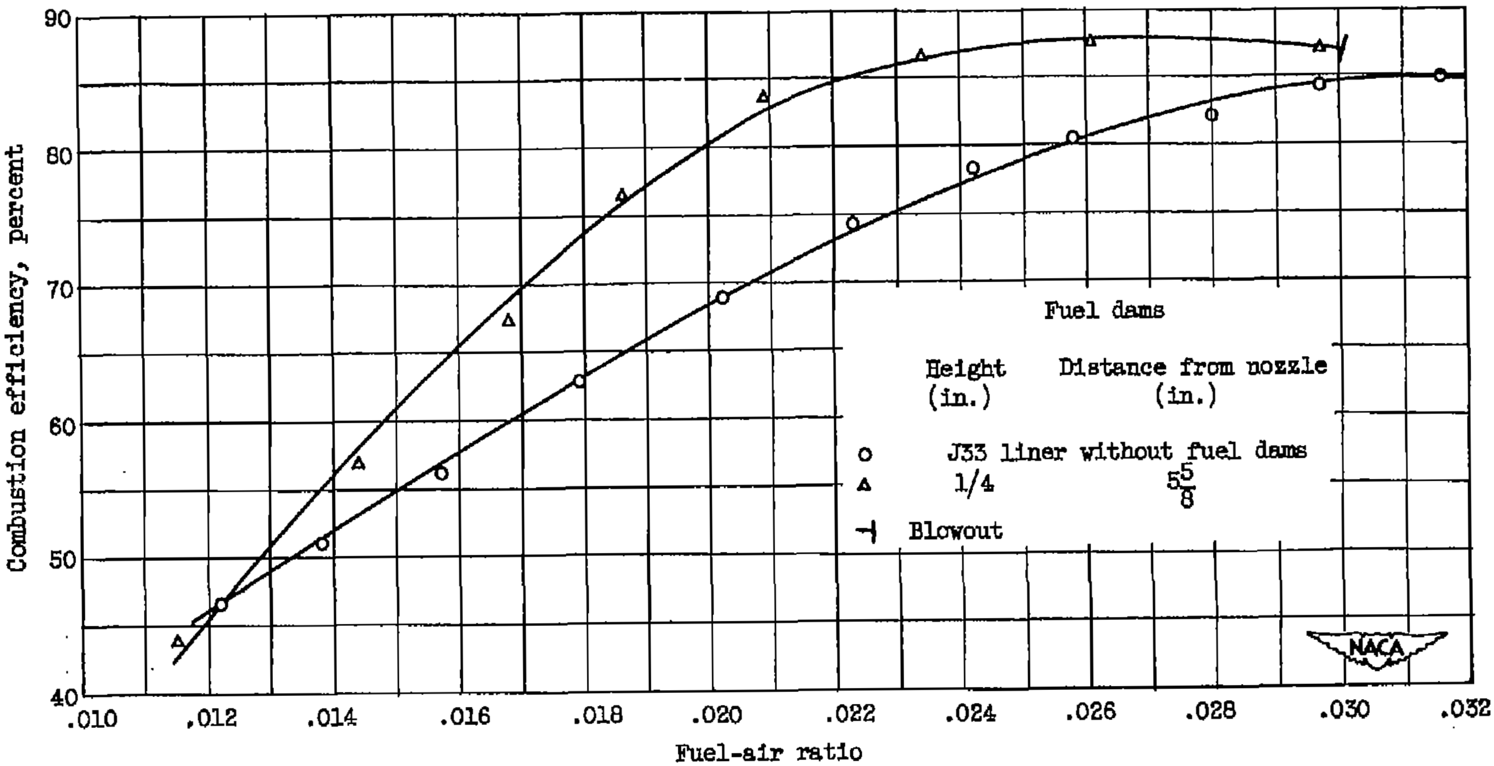

(b) Condition 1. Air-flow rate, 2.78 pounds per second per square foot.

Figure 7. - Continued. Effect of fuel dams on combustion efficiency of J33 combustor using 15.3-gallon-per-hour 30°-spray-angle nozzle at various air-flow rates and fuel-air ratios. Inlet-air pressure, 15 inches of mercury absolute; inlet-air temperature, 268° F; fuel, MIL-F-5624A, grade JP-4.

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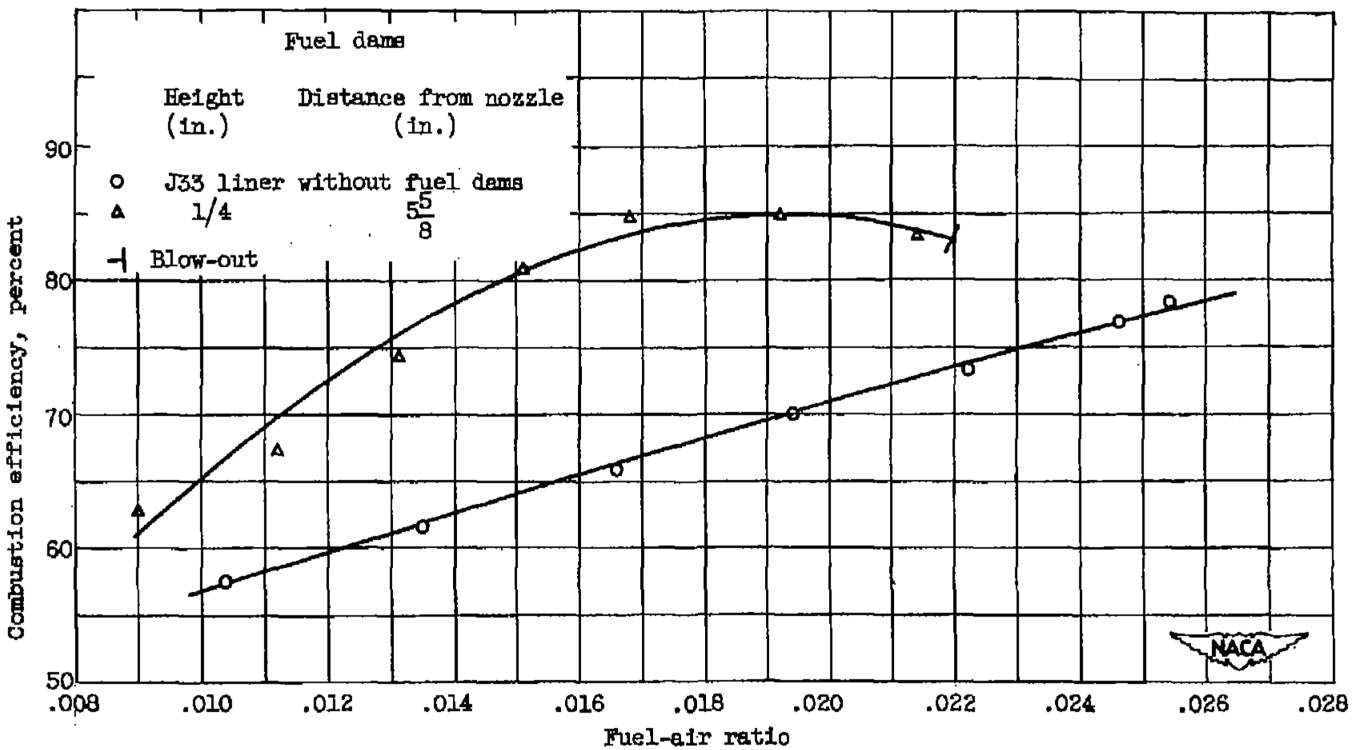

(c) Condition 4. Air-flow rate, 3.62 pounds per second per square foot.

Figure 7. - Concluded. Effect of fuel dams on combustion efficiency of J33 combustor using 15.3-gallon-per-hour 30°-spray-angle nozzle at various air-flow rates and fuel-air ratios. Inlet-air pressure, 15 inches of mercury absolute; inlet-air temperature, 268° F; fuel, MIL-F-5624A, grade JP-4.

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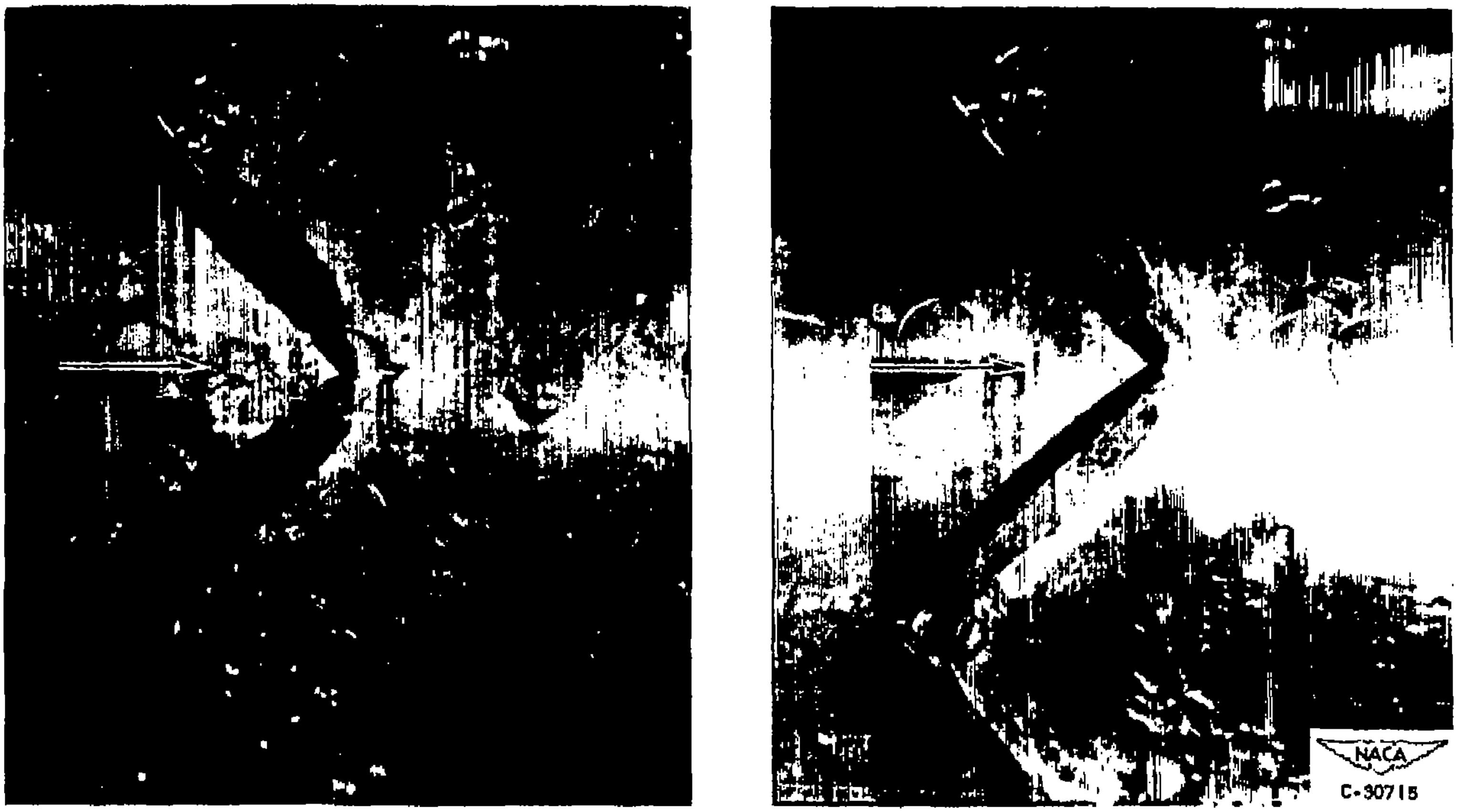
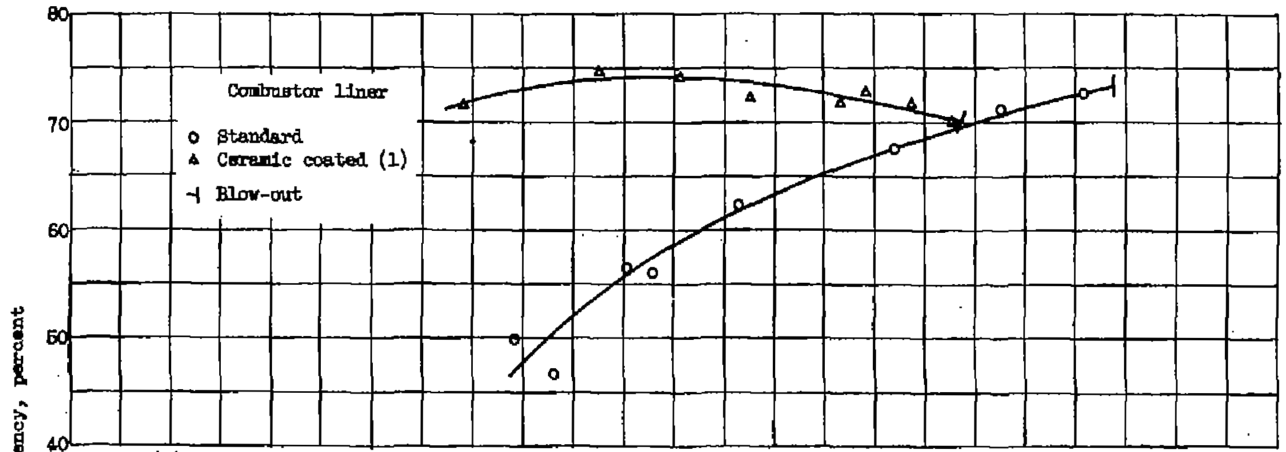


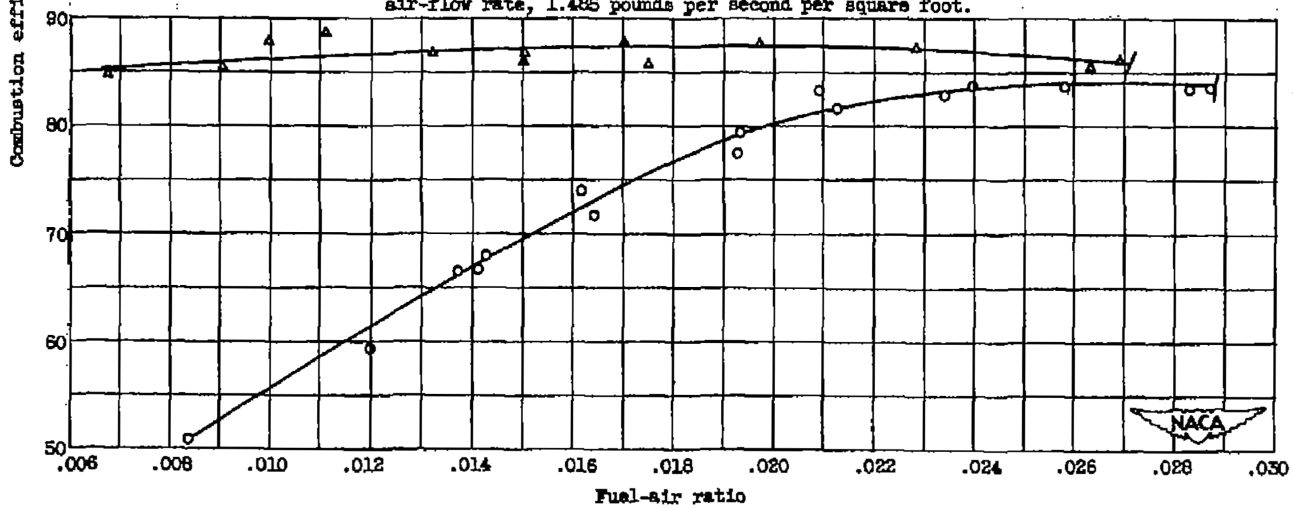
(a) Nozzle, 40 gallons per hour, 80° spray angle; water-flow rate, 25 pounds per hour.

(b) Nozzle, 15.3 gallons per hour, 30° spray angle; water-flow rate, 30 pounds per hour.

Figure 8. - Transparent combustor equipped with two fuel dams and two different fuel nozzles. Cold-flow inlet-air conditions: pressure, 15 inches mercury absolute; temperature, 85° F; flow rate, 2.14 pounds per second per square foot.



(a) Condition 2. Inlet-air pressure, 8 inches of mercury absolute; inlet-air temperature, 268° F; air-flow rate, 1.485 pounds per second per square foot.



(b) Condition 3. Inlet-air pressure, 15 inches of mercury absolute; inlet-air temperature, 268° F; air-flow rate, 2.14 pounds per second per square foot.

Figure 9. - Effect of ceramic coating (1) on combustion efficiency of J33 combustor at several inlet-air conditions. Fuel, MIL-F-5624A, grade JP-4; nozzle, 40 gallons per hour, 80° spray angle.

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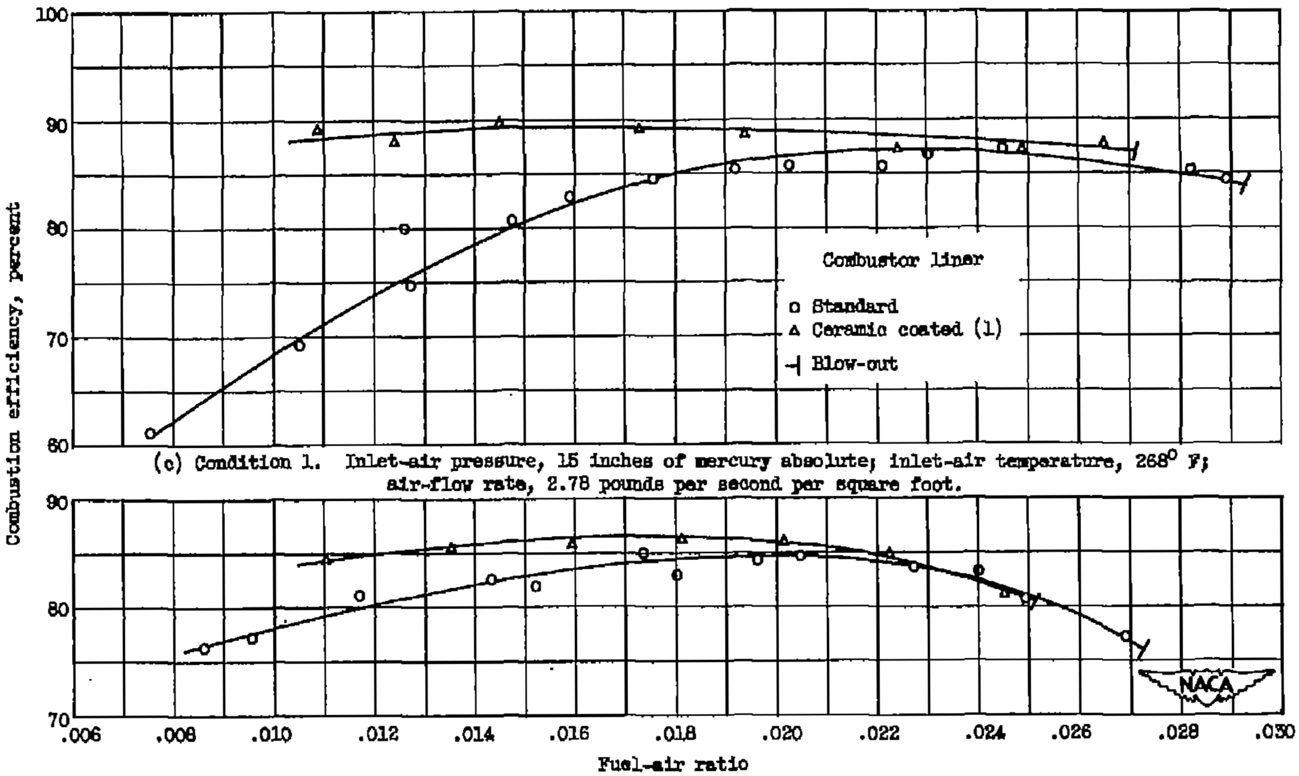

(c) Condition 1. Inlet-air pressure, 15 inches of mercury absolute; inlet-air temperature, 268° F; air-flow rate, 2.78 pounds per second per square foot.

(d) Condition 4. Inlet-air pressure, 15 inches of mercury absolute; inlet-air temperature, 268° F; air-flow rate, 3.62 pounds per second per square foot.

Figure 9. - Concluded. Effect of ceramic coating (1) on combustion efficiency of J35 combustor at several inlet-air conditions. Fuel, MIL-F-5624A, grade JP-4; nozzle, 40 gallons per hour, 80° spray angle.

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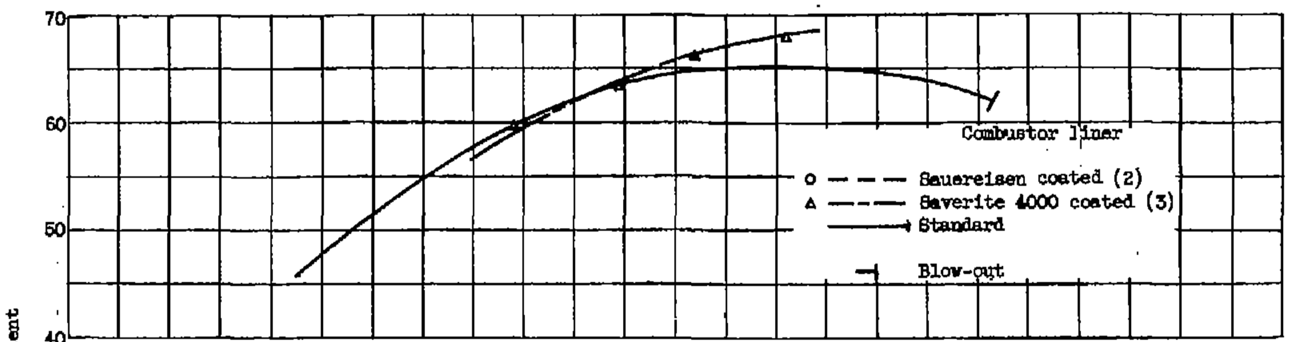
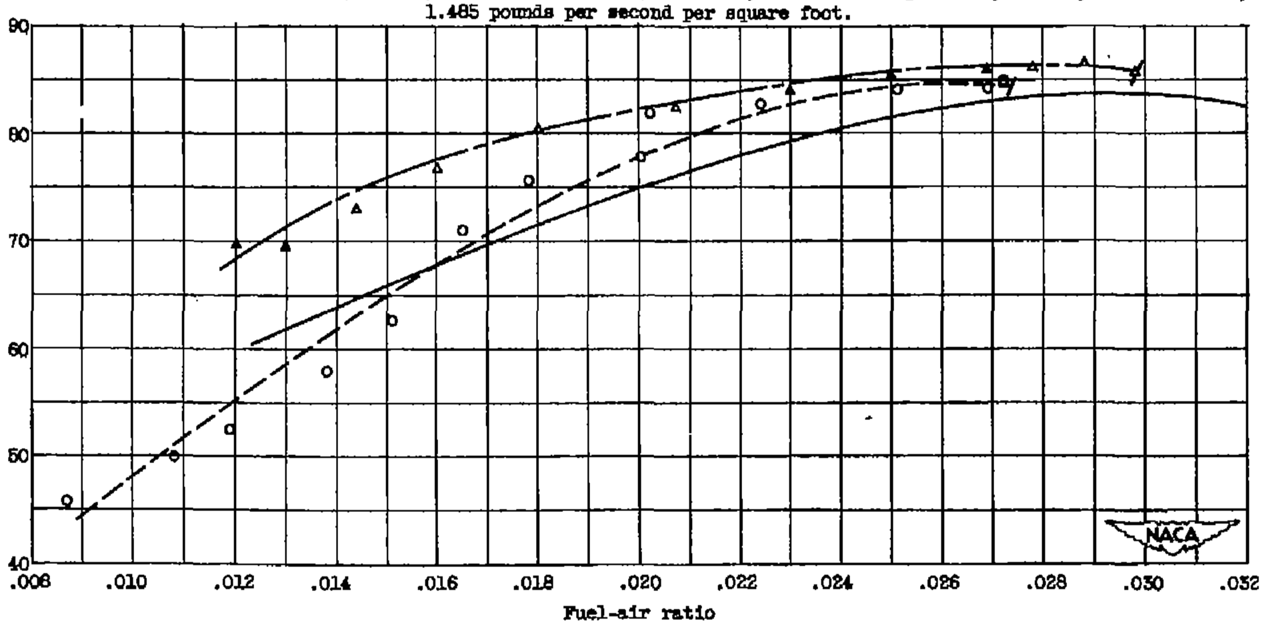


(a) Condition 2. Inlet-air pressure, 8 inches of mercury absolute; inlet-air temperature, 268° F; air-flow rate, 1.485 pounds per second per square foot.



(b) Condition 3. Inlet-air pressure, 15 inches of mercury absolute; inlet-air temperature, 268° F; air-flow rate, 2.14 pounds per second per square foot.

Figure 10. - Effect of ceramic coatings (2) and (3) on combustion efficiency of J33 combustor at several inlet-air conditions. Fuel, MIL-F-5624A, grade JP-4; nozzle, 40 gallons per hour, 80° spray angle.

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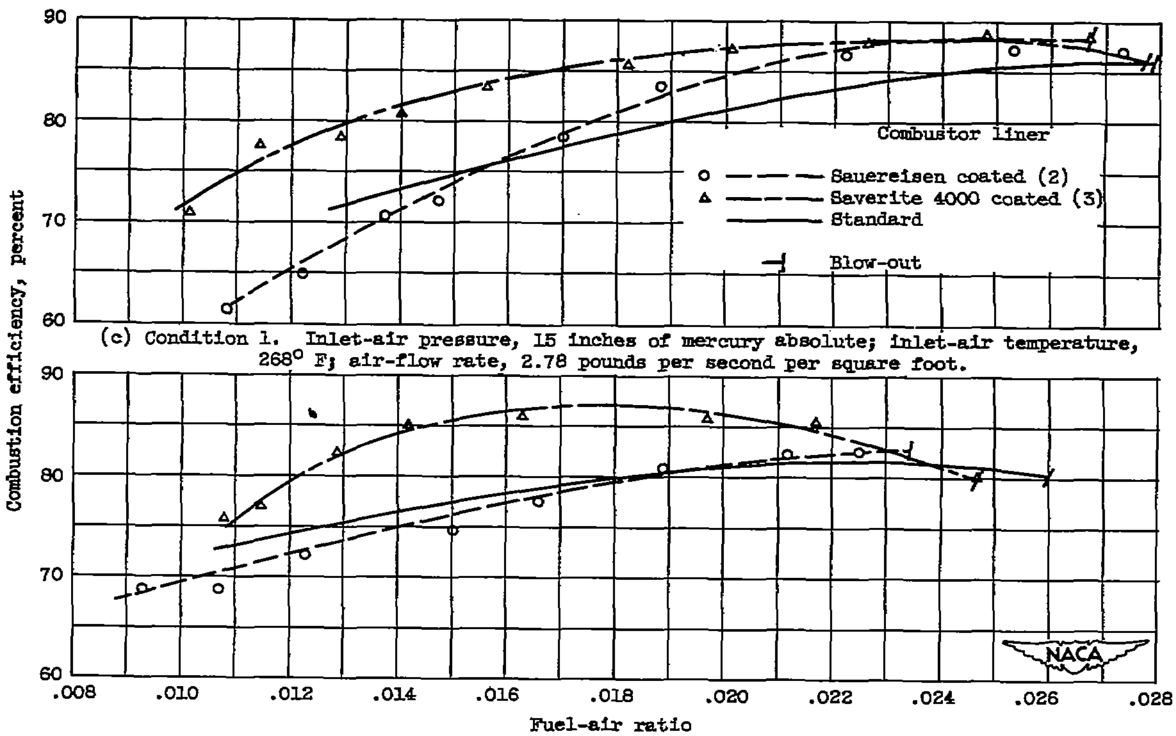
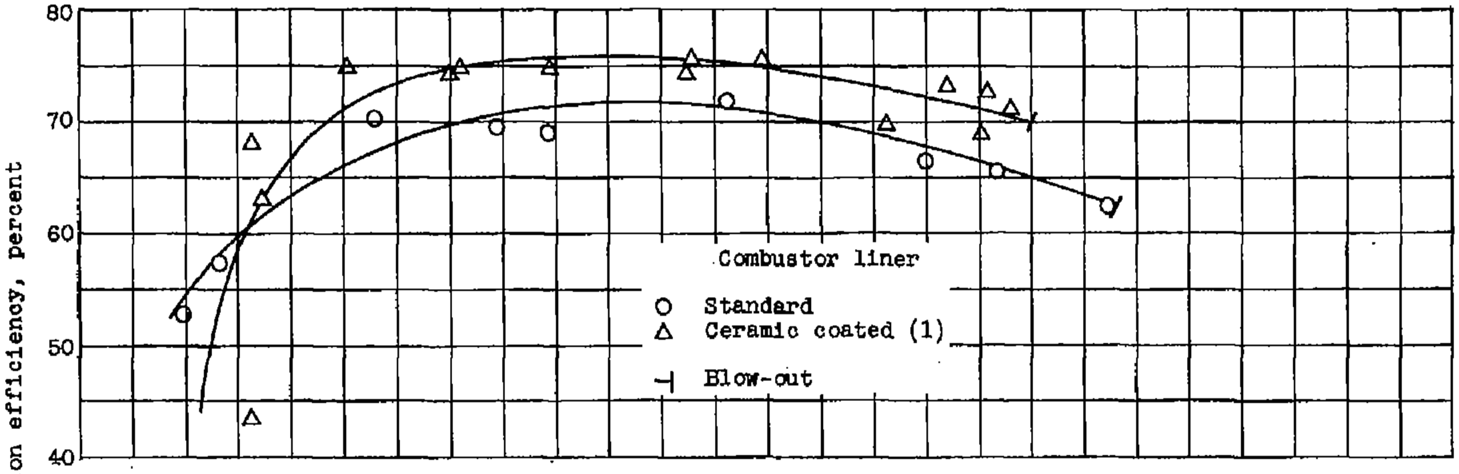


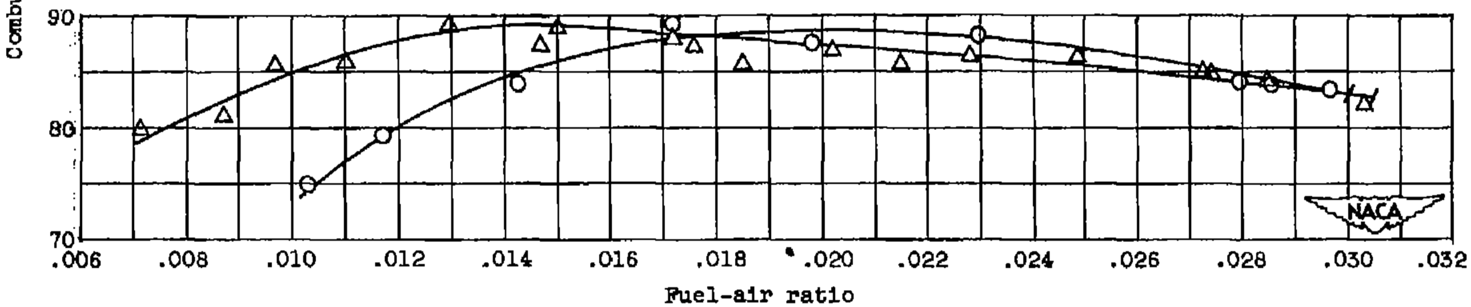
(c) Condition 1. Inlet-air pressure, 15 inches of mercury absolute; inlet-air temperature, 268° F; air-flow rate, 2.78 pounds per second per square foot.

(d) Condition 4. Inlet-air pressure, 15 inches of mercury absolute; inlet-air temperature, 268° F; air-flow rate, 3.62 pounds per second per square foot.

Figure 10. - Concluded. Effect of ceramic coatings (2) and (3) on combustion efficiency of J33 combustor at several inlet-air conditions. Fuel, MIL-F-5624A, grade JP-4; nozzle, 40 gallons per hour, 80° spray angle.



(a) Condition 2. Inlet-air pressure, 8 inches of mercury absolute; inlet-air temperature, 268° F; air-flow rate, 1.485 pounds per second per square foot.



(b) Condition 3. Inlet-air pressure, 15 inches of mercury absolute; inlet-air temperature, 268° F; air-flow rate, 2.14 pounds per second per square foot.

Figure 11. - Effect of ceramic coating (1) on combustion efficiency of J47 combustor at several inlet-air conditions. Fuel, MIL-F-5624A, grade JP-4; duplex fuel nozzle.

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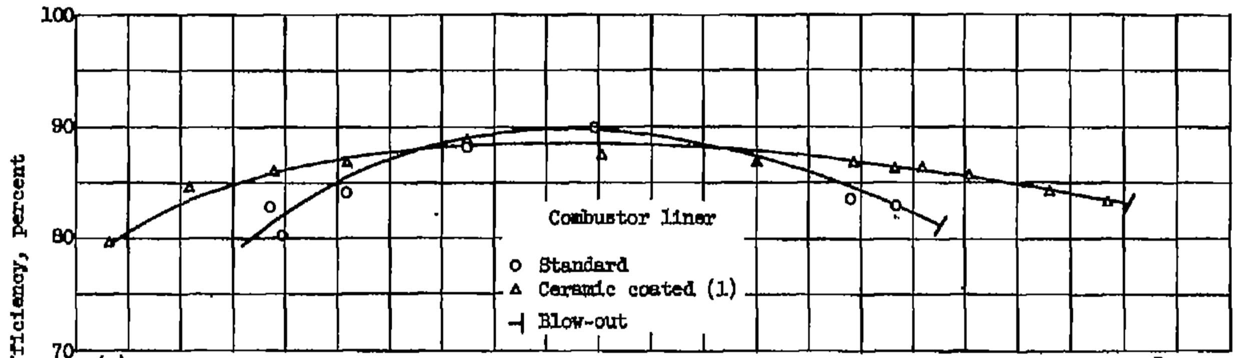
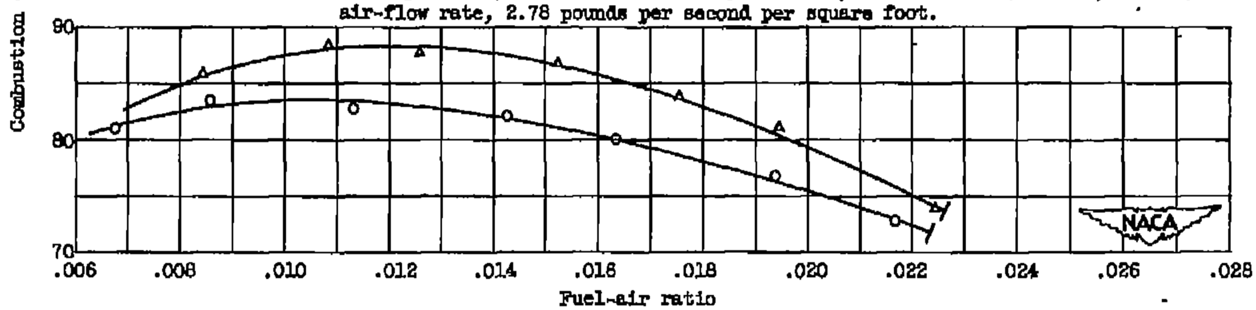
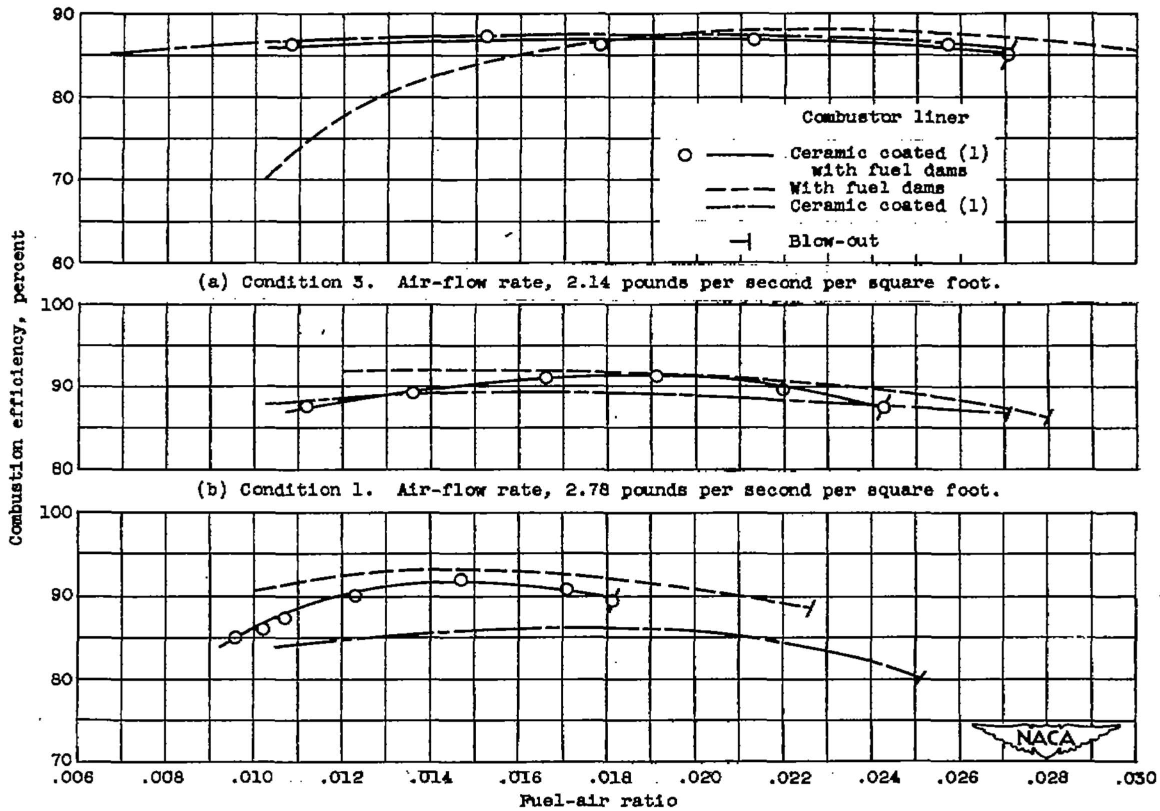


(c) Condition 1. Inlet-air pressure, 15 inches of mercury absolute; inlet-air temperature, 268° F; air-flow rate, 2.78 pounds per second per square foot.



(d) Condition 4. Inlet-air pressure, 15 inches of mercury absolute; inlet-air temperature, 268° F; air-flow rate, 3.62 pounds per second per square foot.

Figure 11. - Concluded. Effect of ceramic coating (1) on combustion efficiency of a J47 combustor at several inlet-air conditions. Fuel, MIL-F-5624A, grade JP-4; duplex fuel nozzle.



(c) Condition 4. Air-flow rate, 3.62 pounds per second per square foot.

Figure 12. - Comparison of combustion efficiencies obtained with ceramic-coated (1) liner, liner with fuel dams, and ceramic-coated (1) liner with fuel dams in J33 combustor at several air-flow rates. Inlet-air pressure, 15 inches of mercury absolute; inlet-air temperature, 268° F; fuel, MIL-F-5624A, grade JP-4; nozzle, 40 gallons per hour, 80° spray angle.

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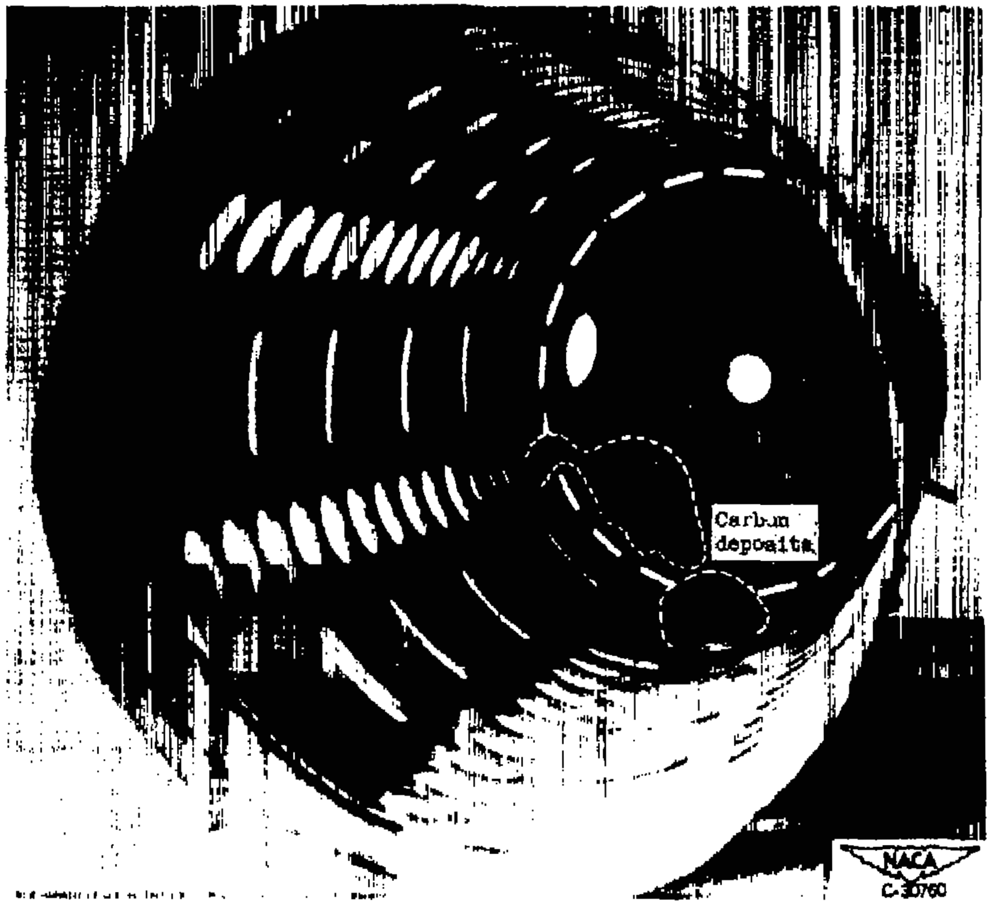

Figure 13. - Carbon deposition in ceramic-coated (1) J33 combustor liner after 4 hours of operation at conditions simulating 90 percent normal engine rotational speed, zero Mach number, and 20,000-foot altitude.

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SECURITY INFORMATION

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